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Estuarine Research Report 35

Evaluation and Development of Techniques to Map Macroalgae in the Avon-Heathcote Estuary Ihutai

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Cover photograph: View of Avon-Heathcote Estuary, looking south towards the Port Hills (photograph Marney Brosnan). Note *Ulva* (sea lettuce) in foreground.

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Executive Summary

1. Seasonal macroalgal blooms are a problem for bays and estuaries worldwide where nutrient runoff from human occupation and development occurs. Eutrophication in the Avon-Heathocte Estuary, Christchurch, has led to growth in two main macroalgae genera, *Ulva* and *Gracilaria.* The development of the ocean outfall provides an opportunity for a substantial macroalgae reduction in the estuary due to decreased nutrient inputs.

2. Ground-based macroalgal surveys to identify cover and biomass have been carried out over the last 60 years at the Avon-Heathcote Estuary. These surveys have successfully identified gross macroalgal cover (mostly green algae distribution), although inconsistent sampling sites, varying species group classifications, differing methods and incomplete data make comparisons between years difficult. Biomass measurements have not been successful.

3. Modern macroalgal mapping trials in estuaries and bays worldwide have shown the potential of remote sensing technologies in mapping macroalgal coverage. A review of the international literature reveals that mapping the cover of macroalgae was achieved with varying degrees of success.

4. Recent attempts to map macroalgal cover in the Avon-Heathcote Estuary by using satellite imagery and aerial photography were limited by suitable atmospheric conditions, the inability to separate individual macroalgal species and, most importantly, the resolution of the imagery (particularly for satellite imagery).

5. This reports details the results of a field and laboratory analysis programme to develop an improved methodology for mapping coverage and biomass of macroalgae using high-resolution aerial photography and ground-based biological sampling. During the summer of 2008, a series of images were photographed at 1000 ft to capture the 1 km^2 field area and eight predetermined survey sites were randomly sampled.

6. Aerial photography was analysed to determine its usefulness for mapping coverage and biomass of macroalgae in *Environment for Visualising Images (ENVI)*. Supervised classifications produced results that allowed the effective mapping of macroalgal coverage, but biomass was only able to be determined through ground-based biological sampling.

7. Results show that there was high cover and biomass of *G. chilensis* along Humphreys Drive and opposite the Mount Pleasant Yacht Club. Cover and biomass of *U. lactuca* tended to be highest around Sandy Point. Cover of *U. lactuca* extended from Sandy Point down to the Heathcote Channel.

8. A series of recommendations are given for further development of this improved methodology for macroalgae mapping. These recommendations are a direct result of trials in the field. Amongst these is the strong recommendation that macroalgal mapping commence no later than July 2008 in order to obtain data before the ocean outfall is operational.

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Chapter 1: Introduction to the Avon-Heathcote Estuary and Macroalgae

1.1 Background

Over the past 50 years the growth of nuisance macroalgae worldwide has increased markedly in estuaries and bays (Mackenzie 2005). In Christchurch seasonal blooms of nuisance macroalgae occur in the Avon-Heathcote Estuary Ihutai (referred to as the estuary in this report) (Bressington 2003). Amongst other human modifications of the catchment and estuary, the seasonal macroalgal bloom has been attributed to the combination of the treated wastewater discharge into the estuary during warm summertime conditions. That is, the growth rates of the algal species involved, including those of the two dominant genera *Ulva* and *Gracilaria*, vary seasonally as a function of temperature and nutrient inputs (Knox 1992). Nutrient enrichment of an ecosystem by human activities is referred to as eutrophication (Knox and Kilner 1973). Knox and Kilner (1973) recognise that phosphorus and nitrogen in treated sewage are the main contributors to the eutrophication of estuarine waters. Algae in particular thrive in high nutrient environments, which results in extensive macroalgal growth (Nelson and Patuawa 2007). With the development of the ocean outfall, due for completion in 2009, waste water will be removed from the Avon-Heathcote Estuary and, instead, discharged into the open sea. It has been suggested that there will be a reduction of macroalgae in the estuary upon completion of the new outfall (Hawes and O'Brien 2000), although little quality scientific information exists on present cover and biomass of macroalgae and how any reduction could be quantified.

According to the classification scheme of Masselink and Hughes (2003) the Avon-Heathcote Estuary is a shallow bar-built estuary system. Figures 1.1a and b show the location and significant features of the Avon-Heathcote Estuary in Christchurch, New Zealand. It is fed by the Avon and Heathcote rivers. Enclosed by a 4 km long spit, the New Brighton Spit, the estuary is 7.02 km² (Jupp et al. 2007). Approximately 85 % of the estuary is tidal sand and mud flats, which are exposed at low tide (Knox and Kilner 1973). The estuary possesses significant cultural value to local Maori, recreational value to water sport enthusiasts, and aesthetic value to the local Christchurch community (Canterbury Regional Council 2002). The Avon-Heathcote Estuary is a place of varied flora and fauna: microscopic plants, microscopic algae, aquatic flowering plants, marginal vegetation, animal life, and macroalgal species (Knox and Kilner 1973).

1.2 Rationale

There have been many attempts to map macroalgal coverage at the Avon-Heathcote Estuary over the past 60 years (with a particular focus on green algae distribution) and to quantify the density of the macroalgae (Knox and Kilner 1973; Bressington 2003). However, there has been no unifying method of mapping both the coverage and biomass of the main macroalgae, various species of *Ulva* and *Gracilaria.* It is of interest to map coverage and biomass of macroalgae in the estuary to view the effects of the new outfall location and provide a basis from which future changes in macroalgae can be monitored. Furthermore a mapping technique may allow the anticipated effects of particular activities on the macroalgae to be evaluated. The establishment of a macroalgae mapping technique may allow assessments of whether or not the macroalgae should be harvested at particular times of the year to control its spread and biomass (Christchurch City Council 2000). These macroalgae are of concern to residents due to the unpleasant smell caused by hydrogen sulphide given off during summer *Ulva* decay (Bruce 1953). Macroalgae can also be a problem for some recreational users of the estuary, particularly kite boarders and wind surfers.

Figure 1.1a Location of Avon-Heathcote Estuary (Adapted from Google Earth 2008).

Figure 1.1b Significant locations and features of the Avon-Heathcote Estuary (Adapted from Google Earth 2008).

1.3 Aims

The primary aim of this project is to recommend an effective methodology for assessing change in the cover and biomass of the different species of macroalgae in the Avon-Heathcote Estuary Ihutai so that changes may be assessed over coming years. The recommended methodology must be scientifically reliable, accurate enough to allow the quantification of significant macroalgal changes, and be achievable with resources currently available to, or easily obtained by, the Christchurch City Council (CCC) monitoring agency.

In order to achieve the primary aim, the four key sub-aims of this project are:

(1) to collate and evaluate existing maps of macroalgal coverage and/or biomass,
(2) to plot changes in biomass and coverage over the last ten years,
(3) to determine and evaluate the mapping techniques used to date, and

(4) to develop an effective methodology for mapping macroalgae, including ground-truthing and the use of high resolution imagery.

1.4 Nuisance Macroalgae

The two nuisance macroalgae of interest in this research are *Ulva* spp. (majority of which is *Ulva lactuca* as shown in Figure 1.2) and *Gracilaria chilensis.* A brief account of both of these macroalgae will be given here, along with description of a similar-looking but non-nuisance algae, *Enteromorpha* spp.

The *Ulva* species comprises a group of seaweeds in the green algae phylum Chlorophyta, which are commonly referred to as sea lettuce (Nelson and Patuawa 2007). *Ulva* plants have thalli 2 to 10 cm in length with fronds that radiate from the base (Steffensen 1974). There is morphological seasonal variability in *Ulva* characteristics (Steffensen 1974). In spring and early summer, fronds elongate, and where they are attached to secure surfaces such as sediment, they grow up to 1 m in length (Steffensen 1974). In summer and early autumn, plants will begin to fragment, which results in drift algae (Steffensen 1974).

Figure 1.2 *U. lactuca* (photograph M. Brosnan 2008).

Enteromorpha species are also in the green algae phylum Chlorophyta (Figure 1.3) and are superficially similar in appearance to *Ulva,* although their plants may be tubular, branched or simple (Adams 1994). According to Knox and Kilner (1973) *Enteromorpha* have a similar growth pattern, but distinctly different seasonal distribution, to *Ulva.* Although *Enteromorpha* and *Ulva* can be distinguished in the field, this distinction would not be possible using high resolution imagery.

List of acronyms (listed in alphabetical order)

ANOVA	Analysis of variance
AP	Aerial photography
CCC	Christchurch City Council
ECAN	Environment Canterbury
EMP	Estuary Monitoring Protocol
EOS (Camera)	Electro-Optical System
ERDAS	Earth Resources Data Analysis System
ESRI	Environmental Systems Research Institute
FCIR	False colour infra-red
GCP	Ground Control Point(s)
GIS	Geographic Information System(s)
GPS	Global Positioning System(s)
IMU	Inertial Measurement Unit
IR	Infrared
JPEG	Joint photographic experts group(s)
NDVI	Normalised Difference Vegetation Index
NIWA	National Institute of Water and Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
RS	Remote sensing
SAS	Statistical Analysis System
SAV	Submerged aquatic vegetation
SPAN	Synchronized Position Attitude and Navigation
SPOT	Satellite Pour l'Observation de la Terre
TIFF	Tagged Image File Format
USA	United States of America

Figure 1.3 *Enteromorpha* (Ocean Globe Marine Science Centre 2001).

G. chilensis is in the red algae phylum Rhodophyta (Figure 1.4). This branching alga appears reddish-brown in situ. According to URS New Zealand (2001), up to one third of the estuarine *G. chilensis* population can occupy the Avon-Heathcote channels. According to Knox (1986), *G. chilensis* can grow as isolated plants attached to solid surfaces such as rocks and shells or as aggregations that anchor in the mud. *G. chilensis* reproduces sexually while *Ulva* reproduces asexually (Knox 1986). *G. chilensis* is able to tolerate a high degree of exposure to air compared with the *Ulva* species which, like many green algae, are prone to dessication (Steffensen 1974).

Figure 1.4 *G. chilensis* (Guiamarina 2007).

1.5 Development of the Ocean Outfall

The north-western boundary of the Avon-Heathcote Estuary is location to the water treatment ponds (Figure 1.1b), where there is mechanical and chemical treatment of Christchurch city's effluent, as well as some natural ultra violet disinfection. In the mid 1960s, treated waste water began to be discharged into the Avon-Heathcote Estuary only on the outgoing tide, which according to Knox and Kilner (1973), apparently solved the eutrophication problem. In 2001, the CCC applied to Environment Canterbury (ECAN) for an extension of fifteen years to its waste water discharge consent, with treatment, maintenance and upgrades. There were 2500 submissions on this application. The consent was granted only until 2009, and a consequent appeal by the CCC to the Environment Court failed.

As a result a new, ocean outfall was planned extending 3 km offshore into Pegasus Bay (Figure 1.5). This proposal gained consent in 2005 and construction commenced in June 2007 (Christchurch City Council 2007). The $87 million project is scheduled to be completed by the end of 2008 (Christchurch City Council 2007). It is expected that waste water dilution from the ocean outfall will be far greater than the current dilution in the estuary, and that removal of discharges from this enclosed environment will significantly improve the estuary while having minimal effects in the open ocean (Christchurch City Council 2007). Once the ocean outfall is operational, there is expected to be an increase in dissolved oxygen, gradual decrease in heavy metals and increase in sediment size within the estuary Murphy (2006), which will lead to improvements in the intertidal mud-flat ecosystem through increasing benthic fauna abundance and species (Oreja and Salinas 2003).

Figure 1.5 Ocean outfall pipeline and pump station (Christchurch City Council 2007).

1.6 McCormacks Bay

Figure 1.1b shows the location of McCormacks Bay, which is separated from the main estuary water body by a causeway. In 1907 a tram causeway was built across the tidal flats and this was later widened in 1933 (Murphy 2006). As a result of this modification, there has been significant alteration in water flow patterns, namely a reduction in the inflow and outflow of freshwater to the bay from the adjacent Heathcote Channel (Murphy 2006). As a result, the enclosed, stagnant water of McCormacks Bay is a perfect breeding ground for algae. It was shown by Martins et al. (2001) that hydrodynamics are a major factor in controlling green macroalgal blooms. One of the recommendations by Murphy (2006) was to return McCormacks Bay to its pre 1907 state, which would allow inflow and flushing of the bay.

1.7 Environmental Factors

One of the most influential physical factors on macroalgal growth is temperature. There appears to be a correlation between temperature and macroalgal growth at the Avon-Heathcote Estuary (Knox and Kilner 1973; Steffensen 1974; EOS Ecology 2007). Knox and Kilner (1973) reported less algae cover in 1972 than the three previous years they had carried out surveys. They related the low winter crop to the below average temperatures recorded. Moreover recent studies carried out by the CCC show that there is a correlation between macroalgal growth and temperature, with high levels of macroalgae in the 2001/02 season attributed to warmer and drier conditions compared with more recent years. Warmer winter and spring temperatures in the 2007/08 season have resulted in higher biomass and cover of both macroalgae phyla than has been observed for the past few years.

Wave conditions have a strong influence on macroalgal biomass in the estuary (Steffensen 1974). This is another source of variation in macroalgal biomass on an annual basis. When the wave conditions are calm, drift algae can continue to survive in large quantities, and this will increase the quantity of standing crop in the following summer (Steffensen 1974). It should also be noted that after a major storm, the wave action can greatly change the distribution of algae across the estuary.

Chapter 2: Macroalgal Mapping Methods and Changes

2.1 Introduction

The purposes of this chapter are to:

(1) review the methods used to map macroalgae in the Avon-Heathcote Estuary since the 1950s,
(2) show changes in macrolagal cover since the 1950s,
(3) plot changes within the last ten years in macroalgal cover, and
(4) review findings from recent international literature to determine their relevance towards achieving the fourth objective of the current study; developing a methodology to map macroalgae in the Avon-Heathcote estuary based on high resolution imagery.

2.2 Early Macroalgal Mapping Methods and Changes in the Avon-Heathcote Estuary

Detailed macroalgal surveys have been carried out at the Avon-Heathcote Estuary for over 60 years. According to Bressington (2003), most surveys carried out up until the late 1960s only made broad observations on both algal biomass and distribution. Early measurements of density of algae were based on wet weight even though dry weight biomass is the only reliable method of assessing algae density (Bressington 2003). In the majority of the maps coverage was plotted, but a broad indication of the biomass was given by dividing cover into percentage categories. According to Knox and Kilner (1973) this was the most reliable way of assessing density of macroalgae, although high percentage cover can have high biomass variation. A summary of the changes in cover is shown in Figure 2.1 (Bressington 2003). Incomplete data and inconsistent sampling sites mean that comparisons between years may not be accurately indicative of the changes in macroalgae biomass through time. In the following section previous studies of Avon-Heathcote macroalgae biomass and cover are reviewed.

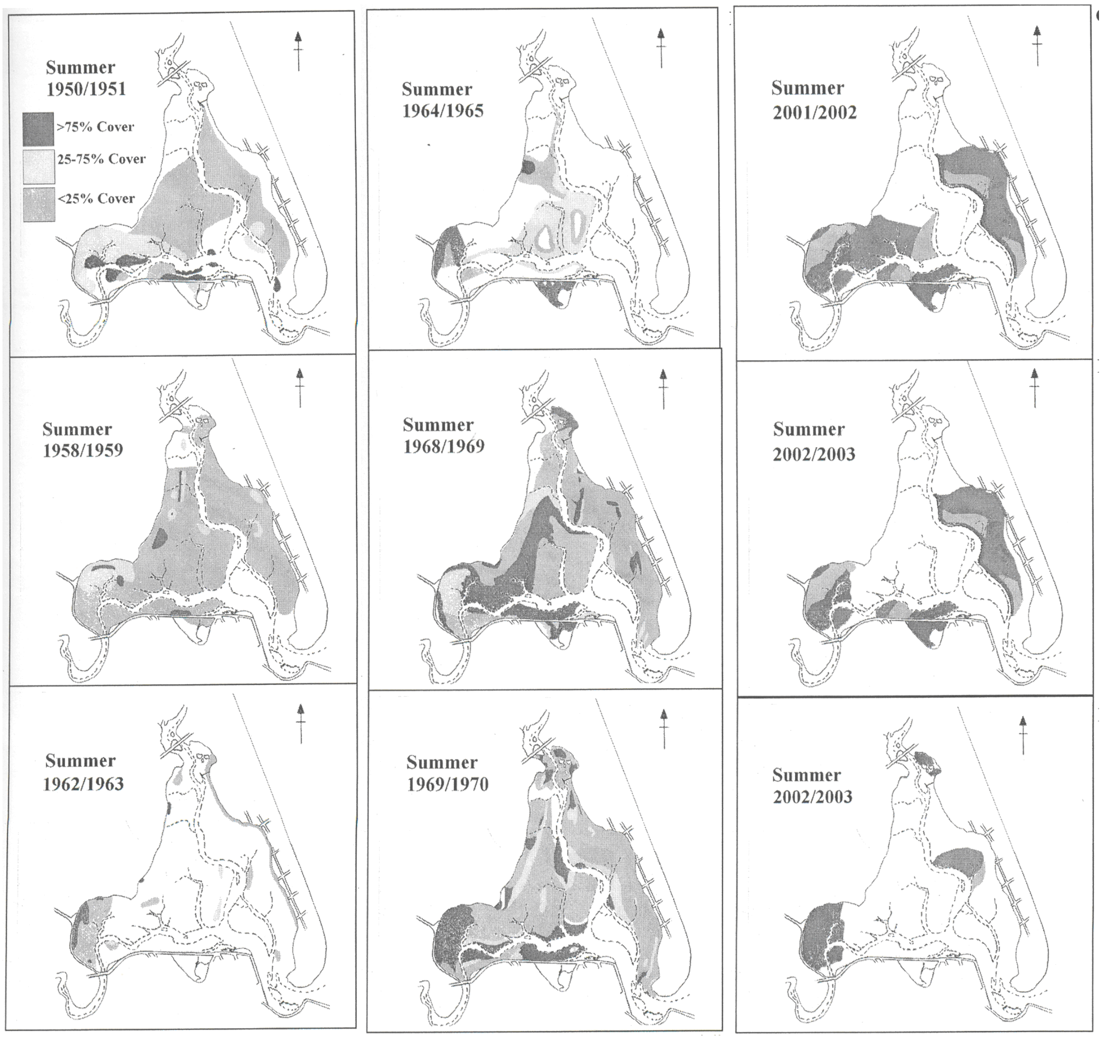


Figure 2.1 Percent cover of green algae (1950-1970), percent cover of *Ulva* spp. (2001-2003) and percent cover of *G. chilensis* (Bressington 2003, p48, 49 and 50).

2.2.1 Review of Literature

Bruce (1953)

Both cover and biomass were surveyed, although mapping involved coverage (Figure 2.2). No methods as to how the mapping was undertaken were mentioned, although Bruce (1953) noted that wet weight biomass was calculated by measuring *Ulva* spp. inside a 1 m² quadrat with a balance.

Bruce (1953) observed in 1950/51 abundant *Ulva* spp. with slightly less *G. chilensis,* and concluded that the *Ulva* spp. had been abundant since 1946. Bruce (1953) reports the reduction in *Ulva* spp. over the winter months, and concludes that the greatest density of *Ulva* spp. was located in places where unattached algae resided. A large majority of the estuary was covered by green algae, with greater than 75 % cover occurring on the estuary side of the causeway and in the low tidal channels opposite Humphreys Drive.

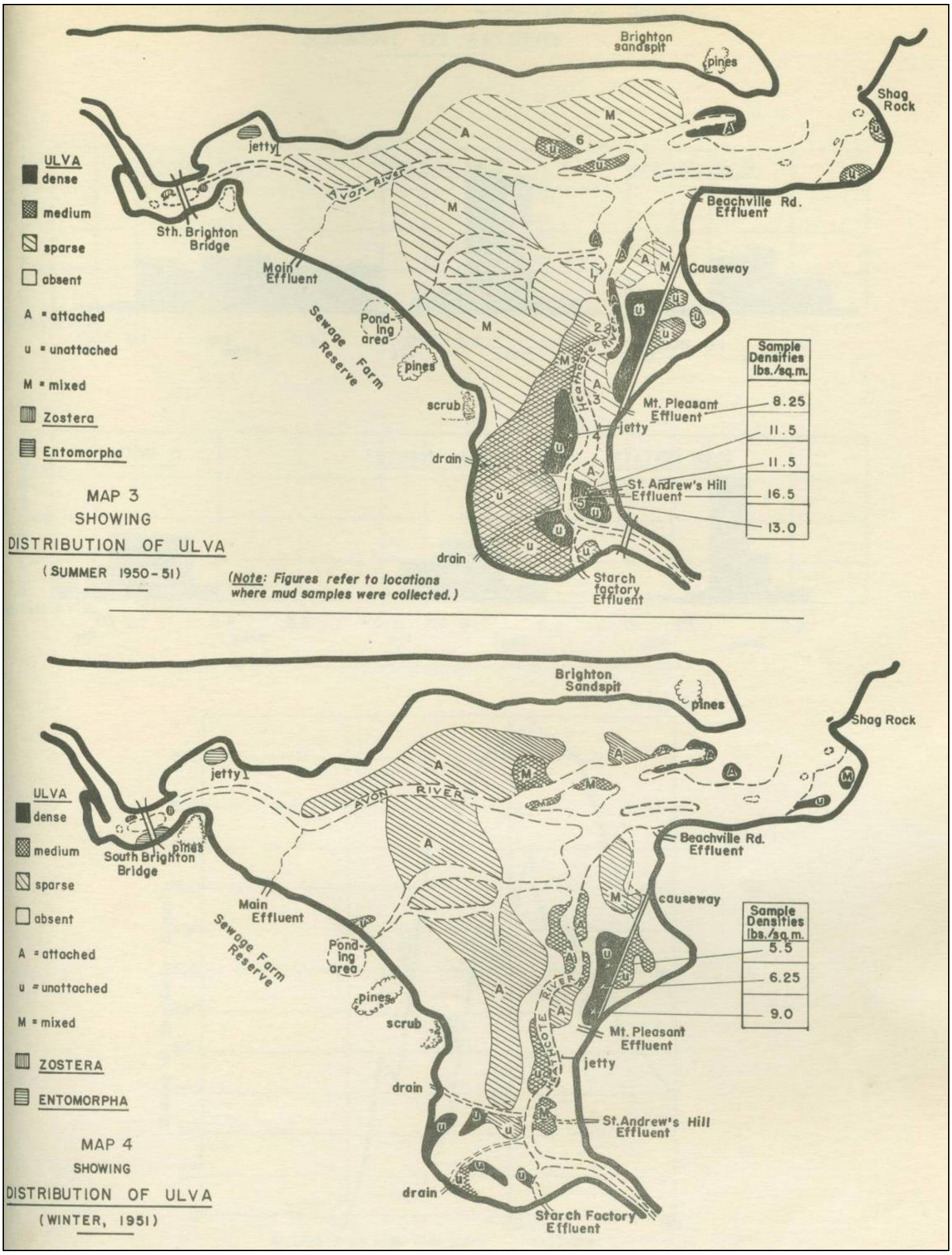


Figure 2.2 Distribution map of *Ulva* in 1950 and 1951 (Bruce 1953, p48).

Williams (1960)

Coverage of green algae, both *Ulva* spp. and *Enteromorpha,* were expressed as:

(1) sparse (up to 2.3 kg/m²),

(2) medium (2.3 kg/m to 4.5 kg/m²) and

(3) dense (over 4.5 kg/m²).

Both cover and biomass were mapped (Figure 2.3). The same method for obtaining density as Bruce (1953) was used. Because there were no criteria specified by Bruce

(1953), it is hard to make comparisons between the maps based on sparse, medium or dense algae.

Williams (1960) noted in 1958/59 that *Ulva* spp. was in approximately equal abundance with *Enteromorpha*. A significant increase in green algae percent cover was observed across the estuary, although around McCormacks Bay and Humphreys Drive percent cover was less. There was a dramatic increase in percentage cover of green algae opposite the oxidation ponds with greater than 75 % cover in some areas.

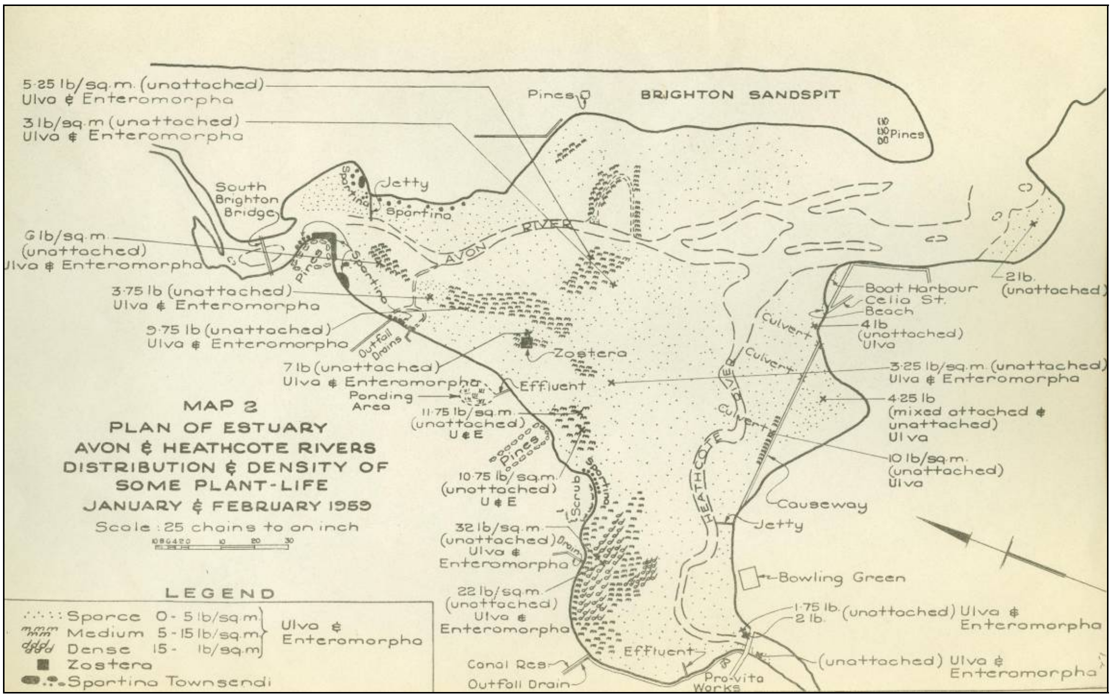


Figure 2.3 Coverage and biomass map of *Ulva* and *Enteromorpha* (Williams 1960, p22).

Rosenberg (1963)

In this study the density of the macroalgae was mapped and plotted (Figure 2.4). The biomass was used to infer the percent cover of *Ulva* spp*.*, *Enteromorpha* and *G. chilensis* (very sparse). Transects were used, along which 1 m² quadrats were placed to weigh the biomass of the macroalgae every half mile around the estuary in addition to sites where outflows from drains occurred.

Rosenburg (1963) observed only sparse *G. chilensis* in 1962/63, with a decrease in both *Enteromorpha* and *Ulva* spp. Within four years of the study carried out by Williams (1960), the estuary appeared to have become devoid of almost any macroalgae. Previous high green algae coverage at McCormacks Bay had disappeared, although high percent cover was still observed at Humphreys Drive. Algae reduction was put down to cyclical fluctuation.

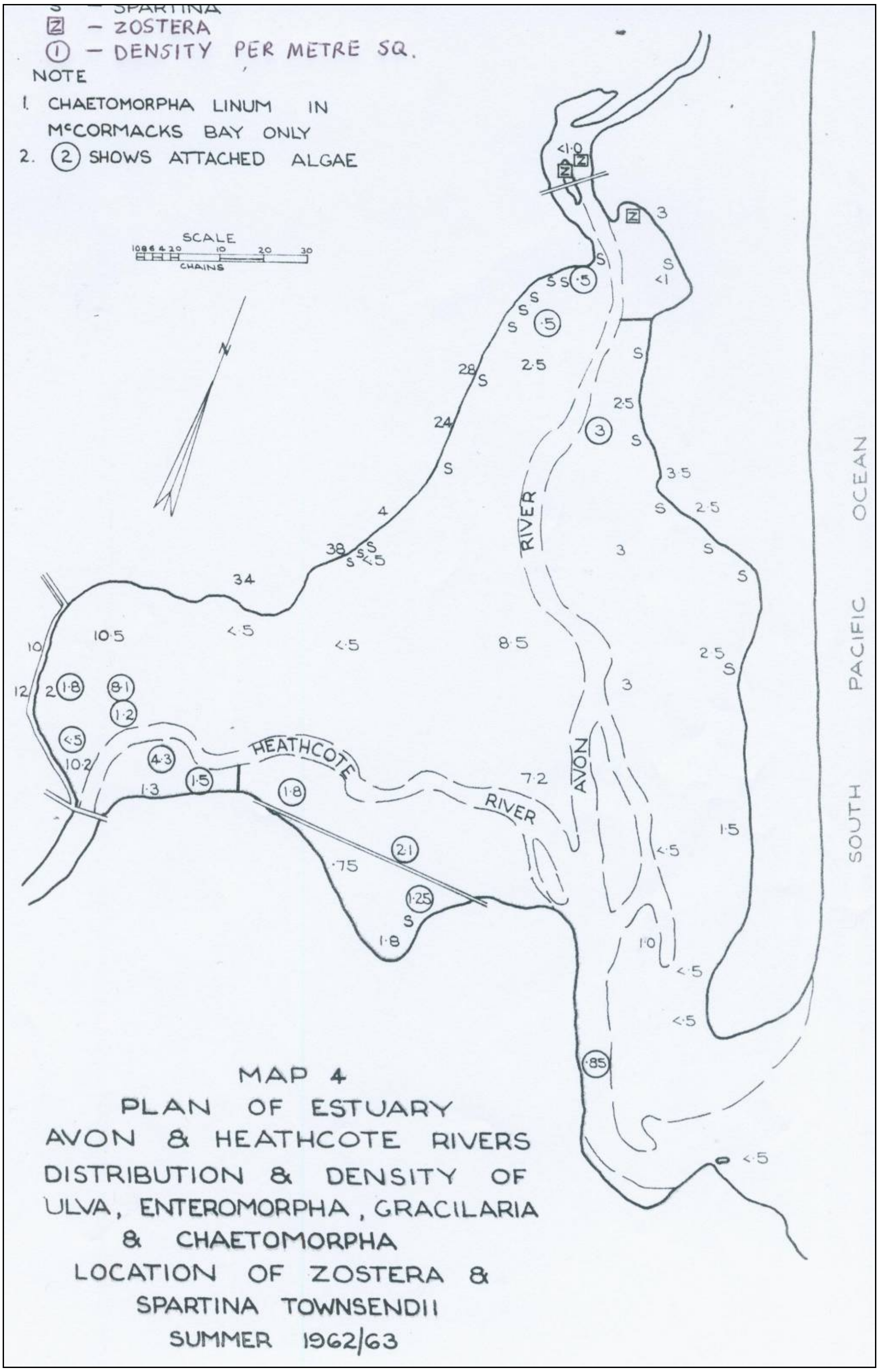


Figure 2.4 Cover and biomass map of *Ulva, Enteromorpha*, *Gracilaria* (Rosenberg 1963, p26).

Webb (1965) and Cameron (1970) in Knox and Kilner (1973)

According to the latter there was an increase in green algae during the mid to late 1960s while *G. chilensis* was scarce. Green algae had increased at McCormacks Bay to greater than 75 % cover and the central part of the estuary had increased green algae cover of between 25 and 75 %. There was a dramatic increase from 1962/63.

The entire estuary was almost covered in macroalgae, with greater than 75 % coverage of green algae at McCormacks Bay, Sandy Point and Humphreys Drive.

Knox and Kilner (1973)

Seasonal distribution surveys were carried out in 1969/70, with 37 stations selected for assessing the algal cover using 0.1m² quadrats every three months. The seaweed was removed, washed to remove mud, molluscs and debris, and then sorted into three genera, *Ulva, Enteromorpha,* or *Gracilaria*. Both wet weights and dry weights were taken. The estuary was mapped for percent cover into three categories at the same time as the other samples were collected. From May 1971 until January 1972, monthly samples using quadrats and transects were done to estimate percent cover of the algae from photographs and an optical point sampler. This was efficient, but not effective in areas of dense algae.

Knox and Kilner (1973) report a high percentage of *Enteromorpha* in the 1969 summer. McCormacks Bay had greater than 75 % cover of green algae, and it is reported that 45 % of the total estuary alga was located in McCormacks Bay in spring. Humphreys Drive and opposite the waste water treatment ponds had high concentrations of algae as usual. Seasonally, there was a very low percentage of algal cover in winter, but this increased steadily in spring and summer where peak cover was reached.

Steffensen (1974)

It is worth noting here that Steffensen (1974) carried out studies on *Ulva* spp. in the Avon-Heathcote Estuary. In addition to ground-based field work, aerial photography was carried out using an aircraft flying at 1000 m. Photomosaics were produced and were compared with existing maps to check the accuracy. Images were taken in both infrared and black and white, which allowed the identification of attached and unattached algae although distinguishing between *Ulva* spp. and *G. chilensis* was not possible. False colour infrared was most successful at determining areas of drift algae.

2.2.2 Summary of Previous Studies

Early macroalgal mapping methods have limited value because there were inconsistent sampling sites, inconsistent density parameters for classification, incomplete data, and a lack of consideration of temporal factors, all of which has undermined valid annual comparisons through time. With this said, the early work provides useful information as to when the different macroalgal species began to grow and broadly in what quantities, which provides an indication of the changes over this 20 year period.

2.3 Modern Macroalgal Mapping Methods and Changes in the Avon-Heathcote Estuary

Over the past ten years there have been several studies to map the macroalgae in the Avon-Heathcote Estuary (Robertson et al. 2002; Bressington 2003; EOS Ecology). Maps were created from data measured in 2000, 2001, 2002 or 2003. This research has involved replotting the changes by digitising macroalgal cover using the

Environmental Systems Research Institute (ESRI) software package *Arc Map* 9.2. These maps give a broad indication of the changes in both *Ulva* and *Gracilaria* (percent) cover over the four years. CCC data provides a general overview of seasonal and annual changes in macroalgae coverage which have been plotted as graphs. The following section reviews recent literature and maps created for mapping macroalgae in the Avon-Heathcote Estuary.

2.3.1 Review of Literature and Existing Maps

Bressington (2003)

In this study all accessible sites around the estuary at low tide were visited on two consecutive days to map the percentage cover of *Ulva* spp. and *G. chilensis*. Photographs were also taken at each site to view the changes in macroalgal cover over time. The percent cover was measured within a 5 m radius at each site. In addition to this, both biomass and coverage were measured throughout the year at six week intervals to observe the seasonal and annual distribution patterns.

Figures 2.5 and 2.6 show that the distribution of *Ulva* spp. in the 2002/03 season was similar to the 2001/02 season. The only notable difference is that in 2001/02, there was coverage around Sandy Point, some of which is between 25 and 75 %, but this had disappeared by the 2002/03 summer. There was still the persistent high percentage of *Ulva* spp. cover at Humphreys Drive and McCormacks Bay in both surveys. *G. chilensis* was mapped individually for the first time in 2002/03 (Figure 2.7). The distribution of *G. chilensis* was found to be significantly less than *Ulva* spp. Humphreys Drive had greater than 75 % cover, with only smaller percentages located opposite Heron Street.

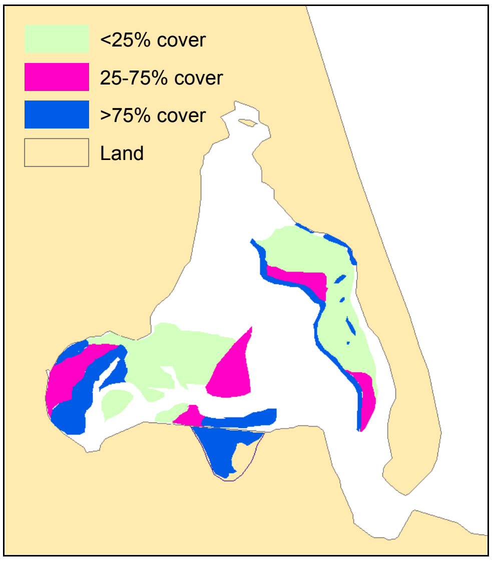


Figure 2.5 *Ulva* spp. distribution in summer 2001/02 (Bressington 2003).

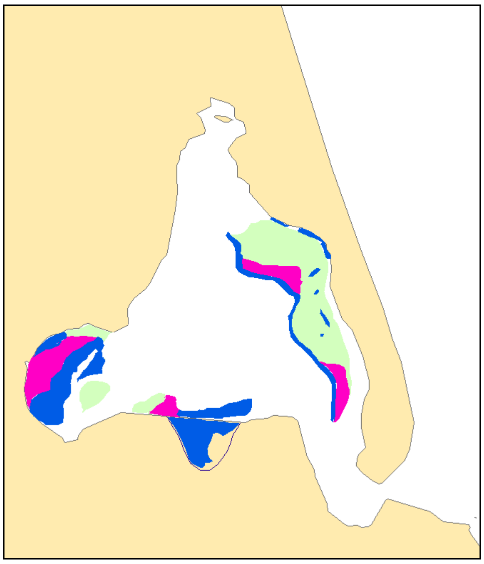


Figure 2.6 *Ulva* spp. distribution in summer 2002/03 (Bressington 2003).

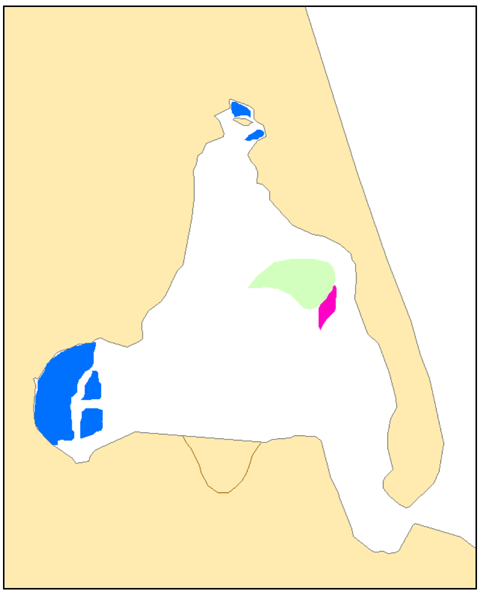


Figure 2.7 *G. chilensis* distribution in summer 2002/03 (Bressington 2003).

Robertson et al. (2002)

Robertson et al. (2002) used existing aerial photography taken by the Canterbury Regional Council on January 9, 2000, at low tide to attempt to map the Avon-Heathcote Estuary macroalgae. The images were scanned to yield a picture element or pixel resolution of 50 cm. A pixel is the smallest areal unit visible in the imagery (Campbell 2002). The images were rectified using at least six prominent landmarks captured by *Trimble Pathfinder Pro* Global Positioning System (GPS). The landmarks were converted to *Arcview* shapefiles and the *Earth Resources Data Analysis System* (ERDAS) was used for rectification and mosaicking of the scanned photograph. Positional accuracy was typically within ± 5 m. Field surveys were carried out to verify the photography and to identify and map features of the estuary, including *Ulva, G. chilensis* and other features such as water and sediment size. These were digitally mapped in *Arcview*.

This map was taken a year before the first study carried out by Bressington (2003) and shows dramatically reduced percent cover of *Ulva* (Figure 2.8). Furthermore the location of *Ulva* on the image is completely different to what Bressington (2003) observed. Bressington (2003) observed abundant *Ulva* spp. at Humphreys Drive and along the New Brighton Spit, but this was not evident in the digitised aerial photography produced by Robertson et al. (2002). *G. chilensis* had a significantly reduced percentage cover in summer 2002/03 compared with 1999/00 (Robertson et al. 2002; Bressington 2003).

Landcare Research (2002)

A satellite image from 2002 was taken on March 14, an hour off low tide. The image was taken from the Satellite pour l'Observation de la Terre (SPOT) 4 satellite. The satellite data was orthorectified to the New Zealand Map Grid. Both *Ulva* (and seagrass) and *Gracilaria* coverage was mapped (Figure 2.9), as well as remaining areas of low tide sea water, emergent area and land vegetation. Some ground truthing was carried out. The ground-truth control samples were identified so a supervised satellite imagery classification could be carried out by Landcare Research. CCC provided Landcare Research with a map which showed the areas of particular ground cover types and this information was used to train the classification (Stella Belliss, Scientist, Landcare Research, *pers. comm.* 2007). This refers to identifying features on an image which can be used as a comparison for classification of features in the image (Canada Centre for Remote Sensing 2005). Training fields were selected according to a visual inspection of the data which were used in the classifications.

In this study *Gracilaria* was mapped in the Humphreys Drive area and there was also the presence of *Gracilaria* opposite the oxidation ponds and Sandy Point (Figure 2.9). This differs from Bressington (2003), because the *Gracilaria* was more abundant in the central part of the estuary in March 2002 than the summer of 2002/03.

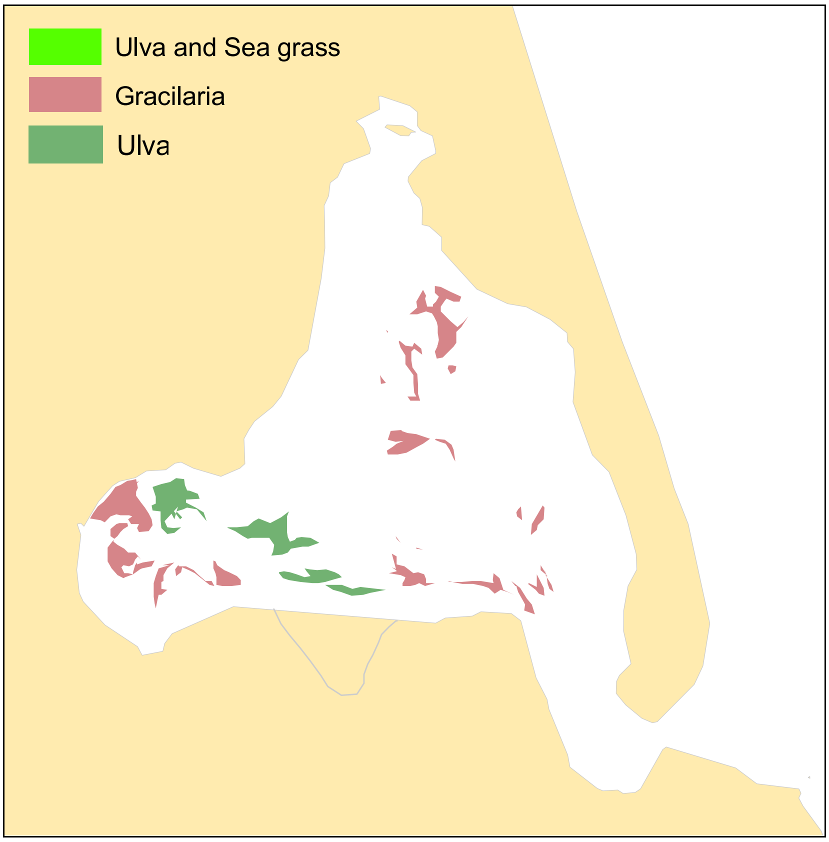


Figure 2.8: *Ulva and Gracilaria* distribution on January 9, 2000 (Robertson et al. 2000).

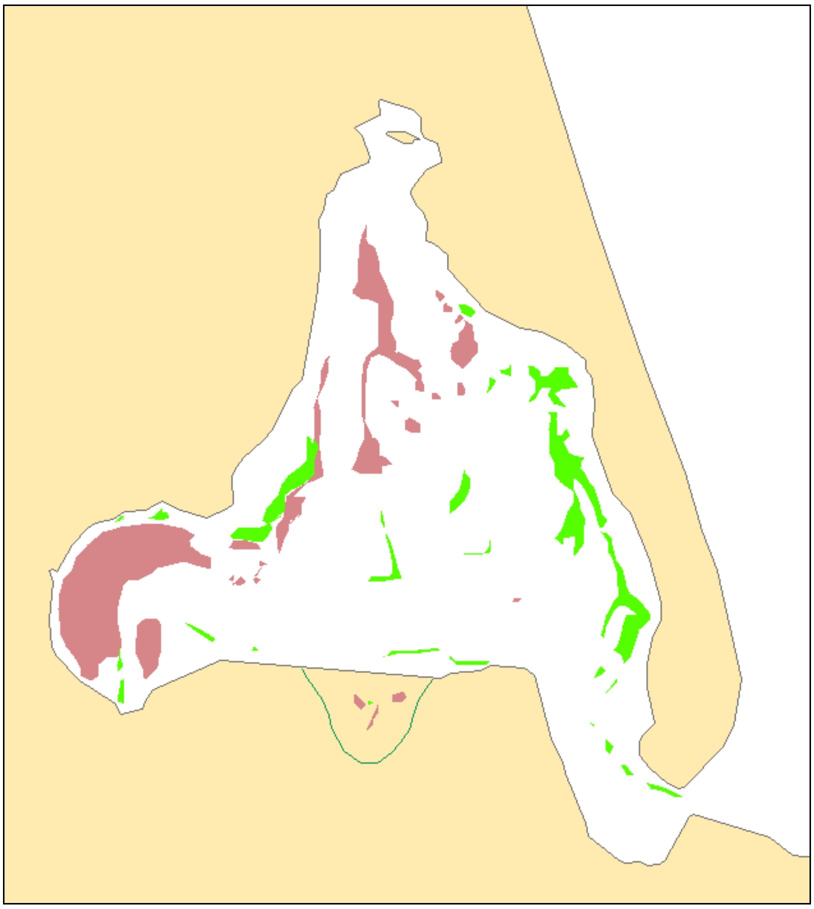


Figure 2.9: *Ulva*, *Gracilaria* and seagrass distribution on March 14, 2002 (Landcare Research 2002).

2.3.2 CCC Monitoring Surveys

2.3.2.1 Background

For the past six summer seasons, the National Institute of Water and Atmospheric Research (NIWA) in conjunction with the CCC, has carried out monitoring surveys for both *Ulva* and *Gracilaria* from 2001/02 to 2006/07. Monitoring of the macroalgae was carried out at seventeen sites at the Avon-Heathcote Estuary (Figure 2.10). These sites were predominantly located on the periphery of the estuary rather than locations randomly located throughout the estuary. This in part was designed to focus on wash-up algae opposite residential areas, which was the council's main concern (Ken Couling, Senior Planning Engineer, CCC, *pers. comm.* 2008). Evidently sites were selected on their predicted biomass and coverage, and not done randomly. At each site, relative elevation was measured, but any change in elevation proved an inconclusive factor in macroalgal cover. Bed material was collected and analysed for particle size and distribution but no patterns were found.

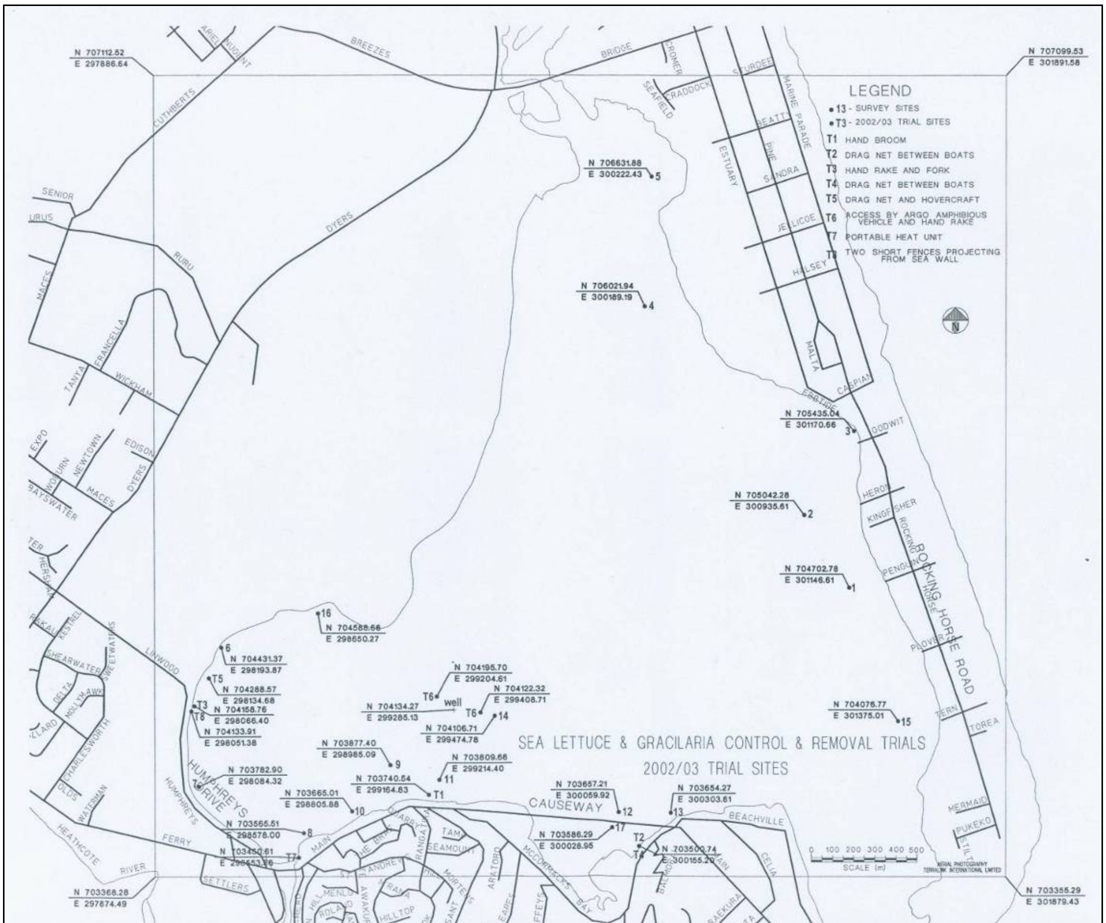
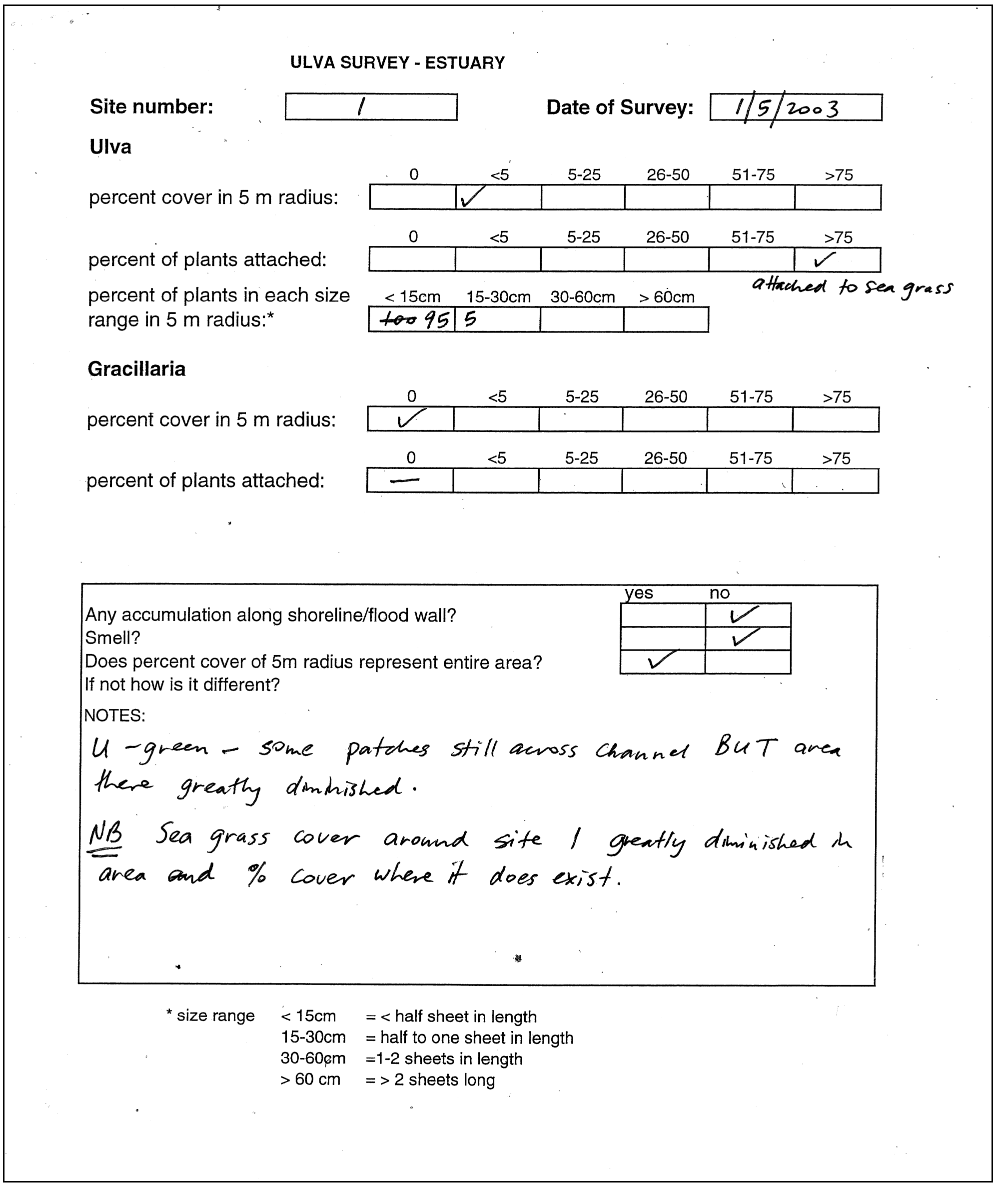


Figure 2.10 CCC monitoring survey sites for 2001 to 2007 (Christchurch City Council Data 2003).

Raw data from CCC monitoring surveys at the Avon-Heathcote Estuary have been transformed into graphs to identify spatial and temporal patterns, both inter and intra-annually. The surveys involved measuring and recording the percent cover of both *Ulva* and *Gracilaria.* The percent cover was measured in a 5 m radius. In addition, attached and unattached algae was measured and recorded, as well as any extra site specific information. Biomass was not measured directly in the surveys. Figure 2.11 shows a typical site survey sheet. The graphs are solely concerned with the percent cover of macroalgae. The macroalgae were placed under one of six percent cover categories. Because of this classification scheme all percentages displayed in the graphs are maximum values. This provides a visually useful way of interpreting the data and assessing general patterns in macroalgal cover.



ULVA SURVEY - ESTUARY

Site number: 1 **Date of Survey:** 1/5/2003

Ulva

	0	<5	5-25	26-50	51-75	>75
percent cover in 5 m radius:		✓				
percent of plants attached:						✓

attached to sea grass

	< 15cm	15-30cm	30-60cm	> 60cm
percent of plants in each size range in 5 m radius:*	~~100~~ 95	5		

Gracillaria

	0	<5	5-25	26-50	51-75	>75
percent cover in 5 m radius:	✓					
percent of plants attached:	—					

	yes	no
Any accumulation along shoreline/flood wall?		✓
Smell?		✓
Does percent cover of 5m radius represent entire area?	✓	

If not how is it different?

NOTES:

U - green - some patches still across channel BUT area there greatly diminished.

NB Sea grass cover around site 1 greatly diminished in area and % cover where it does exist.

* size range
< 15cm = < half sheet in length
15-30cm = half to one sheet in length
30-60cm =1-2 sheets in length
> 60 cm = > 2 sheets long

Figure 2.11 Typical CCC monitoring survey sheet (Christchurch City Council Data 2003). Note the six categories for percent cover classification (0, <5, 5-25, 26-50, 51-75, >75).

2.3.2.2 Observed Seasonal and Annual Changes in Macroalgal Cover

Inter-annually there appears to be some interesting trends in the different species cover percentages. Figure 2.12 shows that October 2001 had a substantially higher percent cover of both *Ulva* and *Gracilaria* compared with other years. There appeared to be a consistent level of *Ulva* over all sites in 2003, 2005 and 2006. There was a dramatic decrease in *Gracilaria* in 2003 from 2001, but 2005 had a higher cover of *Gracilaria* at sites 7 and 8 than 2003 or 2006. There was a slight reduction in *Ulva* cover in 2006 compared with 2005 and there was negligible *Gracilaria* present.

December 2001 had a remarkably high percentage of *Ulva* compared with 2005 and 2006, which were relatively low (Figure 2.13). The percent cover of *Gracilaria* was also very high in 2001, but reduced to very sparse amounts in 2005 and 2006. Survey sites 5, 6, 7 and 8 were high macroalgae cover sites in 2001, all with greater than 75 % cover of both *Ulva* and *Gracilaria.*

Intra-annually there appears to be month to month patterns in cover emerging. These patterns are very important for observing seasonal variation in the extent of macroalgae. In late October of the 2001/02 season, both *Ulva* and *Gracilaria* coverage was moderate, but within two weeks *Ulva* percent cover had increased substantially, while *Gracilaria* cover has remained constant (Figure 2.14 and 2.15). In late November, there was a sudden drop in both *Ulva* and *Gracilaria.* There were no details entered for sites 6, 7 or 8, which are traditional high cover areas. In mid-December there was greater than 75 % coverage of both *Ulva* and *Gracilaria* at sites 5, 6, 7 and 8, but there was a dramatic decline in *Gracilaria* by the end of December to very sparse quantities. In early January there appeared to be a dramatic reduction in both *Ulva* and *Gracilaria* although almost half the sites had no data recorded. In late January *Ulva* and *Gracilaria* cover was similar to the previous week's survey. There was a distinct change in *Ulva* cover at sites 7 and 8, from high to low percent cover. *Gracilaria* cover was higher in early February compared with late February, which was also true for *Ulva.*

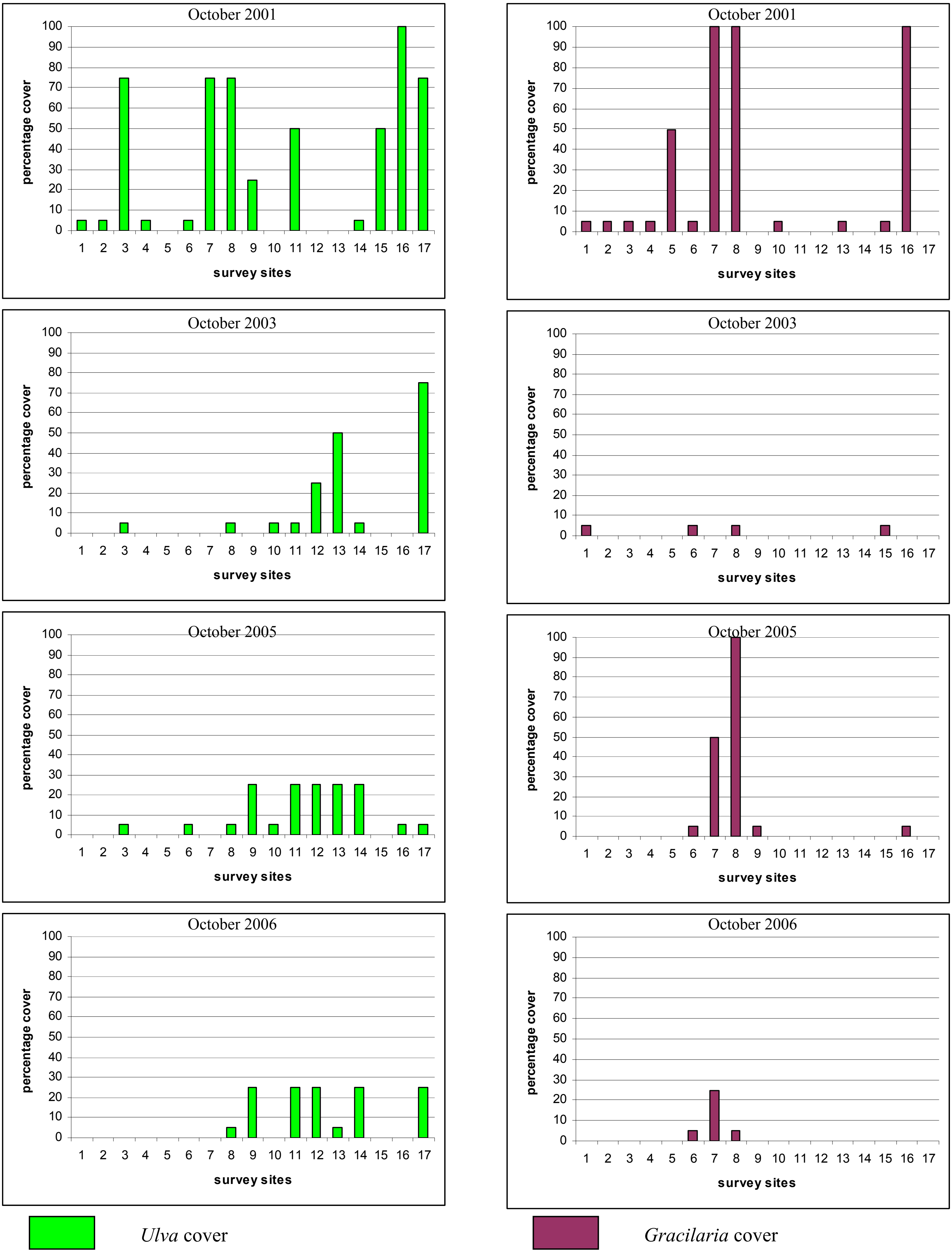


Figure 2.12 Percent cover of *Ulva* and *Gracilaria* for October months from 2001 to 2006 (Christchurch City Council Data 2001-2006).

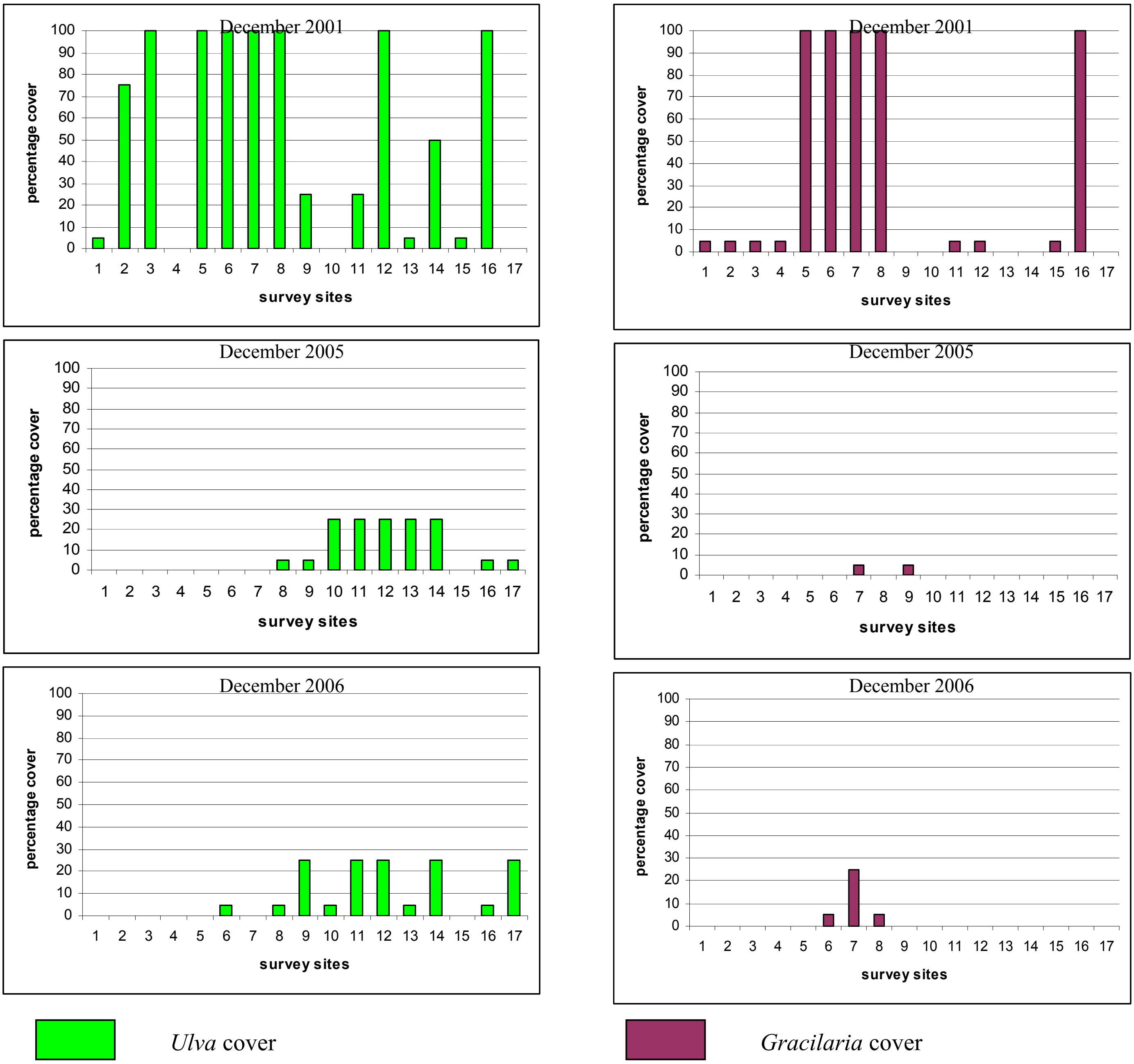


Figure 2.13 Percent cover of *Ulva* and *Gracilaria* for December months from 2001 to 2006 (Christchurch City Council Data 2001-2006).

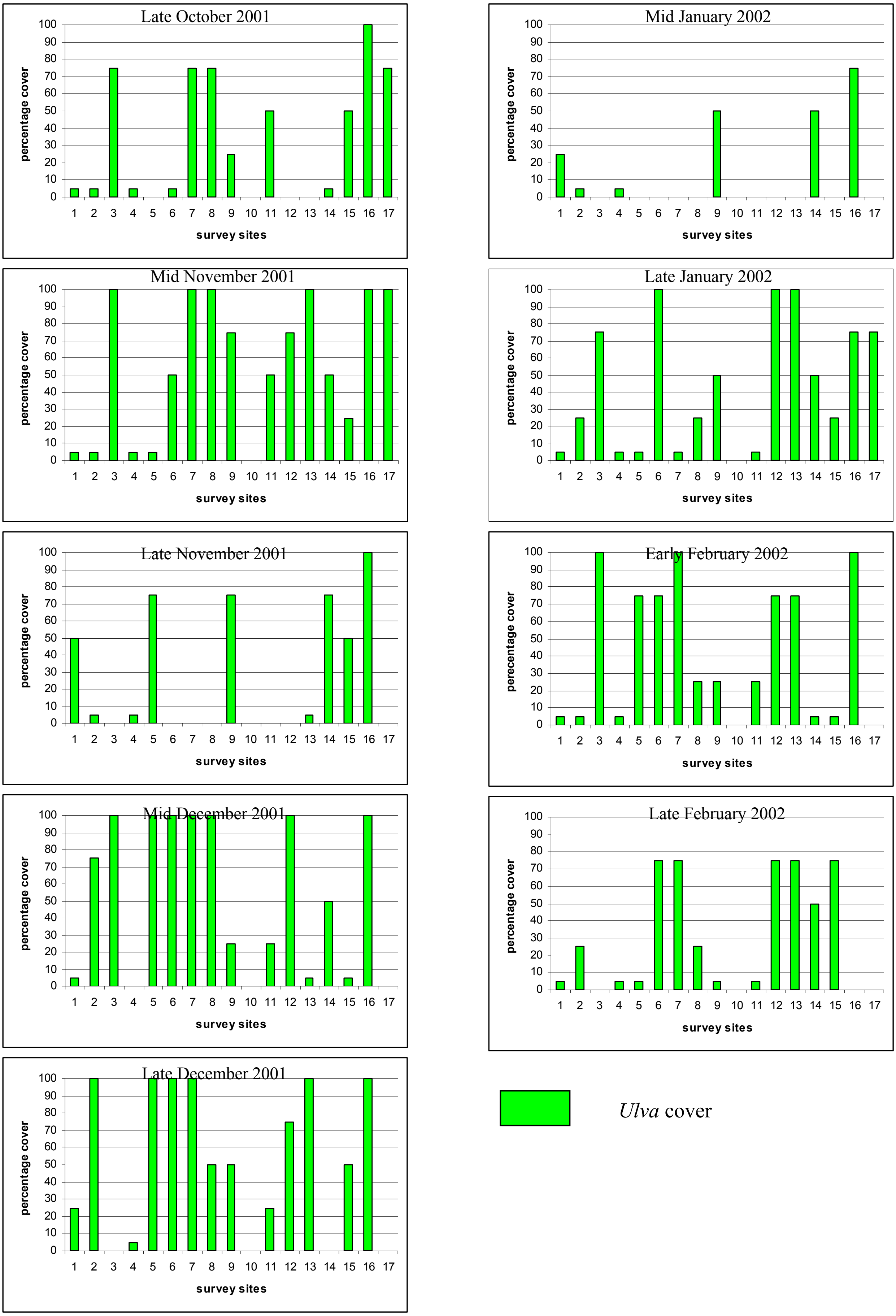


Figure 2.14 Percent cover of *Ulva* throughout the 2001/02 summer season (Christchurch City Council Data 2001-2002).

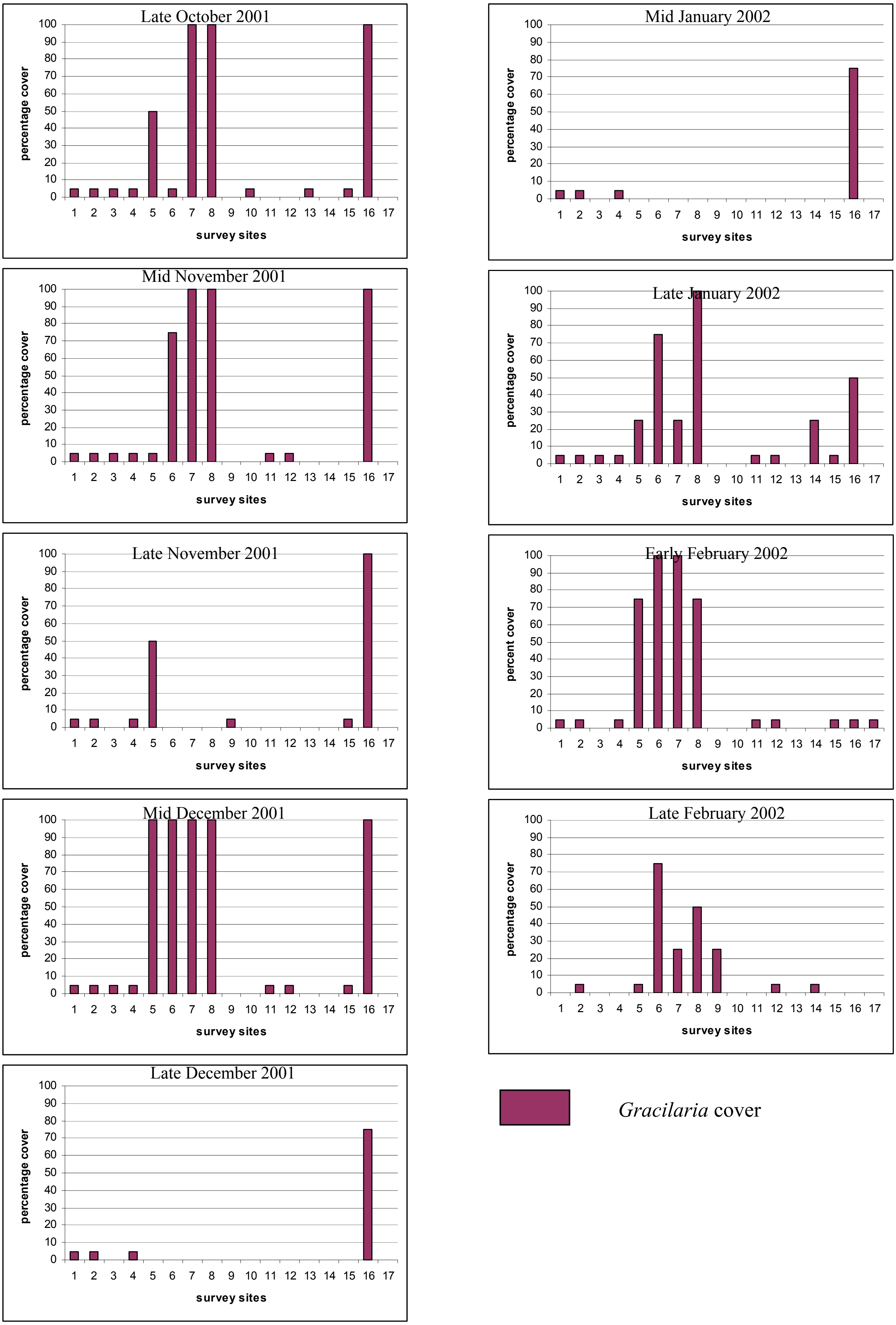


Figure 2.15 Percent cover of *Gracilaria* throughout the 2001/02 summer season (Christchurch City Council Data 2001-2002).

2.3.3 Summary of Recent Studies

Analysis reveals that the surveys carried out by CCC could have been more useful if there was consistency in surveying of sampling sites and complete data sets. Studies have not been carried out on the same dates each year, and not even in the same months as previous years, so at best only broad comparisons can be made. Furthermore, the surveys were carried out over at least two days, which inevitably can lead to error, particularly in locations that had high percentages of unattached macroalgae. Recent maps produced by Robertson et al. (2002), Landcare Research (2002) and Bressington (2003) do not allow comparisons to be made between years because of variations in the timing of mapping.

2.4 International Literature Review of Modern Macroalgae Mapping Methodologies

Within the last fifteen years, there has been a focus on utilising remote sensing techniques to map macroalgae rather than the standard ground-based surveys outlined in the previous sections. Table 2.1 summarises recent macroalgal mapping techniques used internationally. The following sections outline aerial photographic and sea-floor surveying techniques which were or were not successful for mapping macroalgae.

Table 2.1: Summary of literature on modern macroalgal mapping methodologies

Authors	Year of survey	Location	Method	Data capture process	Type of imagery	Extent of ground truthing	How successful was it?	Usefulness to this project
–	1994	Ythan Estuary, Scotland	Vertical AP imagery, GCPs mapped using *Trimble* GPS, images scanned and tiles imported to ERDAS	Model aircraft (with airborne RS platform) at 300-500 m	Black and white IR, colour, colour IR	Limited to measuring GCPs	APs successful at determining areas of macroalgae, sand and mud flats	Data processing techniques and model aircraft could be used in Avon-Heathcote Estuary
Guichard et. al	1997	Method tested on intertidal rocky shore algal community	Standard 35mm camera, remotely controlled from ground level, 2 parallel transects with GCPs measured, 1cm resolution, production of NDVI	6m helium inflated blimp and 80m and 50m flying height	Colour and IR	Extensive ground-truthing using quadrats sampled at same location as GCPs just after AP taken	Accurate at determining biomass, but still some variability within biomass predictions	Considers a way to map biomass using infra-red as well as colour AP
Cole et al.	1999	Rehoboth Bay, Delaware, USA	AP, 4 north to south flight lines with 60% overlap at the ends and 30% at the sides, register image to coordinate system using other spatial data, buoys used as GCPs located by GPS, stretched and rotated images to coordinate system	Aircraft	Colour AP	Limited field surveys	Spatial extent of macroalgae determined, but not in the deep parts of the Bay	Useful for mapping biomass and coverage of macroalgae in shallow areas similar to that of the Avon-Heathcote Estuary
–	2000	Delaware's Inland Bays, USA	Transects used to map the sea floor, with the data coming from the strength/time of acoustic return.	Single beam sonar (acoustic) seafloor classifier	–	None possible	Highly successful because it is a method that can map macroalgae in turbid waters, very fast data processing, leads to efficient harvesting of the macroalgae	Avon-Heathcote Estuary waters at high tide may be deep enough to measure macroalgae using this method
Clinton et al.	2001	Yaquina Bay Estuary, Oregan, USA	Data gathered at low tides and orthorectified to a 20 cm resolution, used a NDVI to help distinguish eelgrass and macroalgae	–	FCIR	–	Successfully distinguished eelgrass and non-vegetated areas from macroalgae	Eelgrass primary focus of the research
Riegl et al.	2002/03	Indian River Lagoon, USA	–	Acoustic seafloor surveys (echo returns) with a 7m survey vessel	–	Extensive field surveys involving macroalgae and seagrass sampling and weighing	Successfully mapped and predicted biomass; still residual error between sparse and dense algae	Better suited for turbid water, but could be used in Avon-Heathcote Estuary channels
Green	2004	Ythan Estuary, Scotland	Existing imagery from 1989, 1992, 1994, 2000 to map macroalgae mats; images were selected, scanned, geocorrected and mosaics created and digitised	AP was taken using light aircraft at 300-500 m	Colour AP	None possible	Distinguishing between macroalgal species difficult, boundaries can be gradual; did find out year to year variations in location	Existing AP of the Avon-Heathcote Estuary could be examined in a similar way
Nezlin et al.	2005	Newport Bay Estuary, Southern California	Imagery was orthorectified and georegistered. Three composite images were created for the three months (between July and October). Images underwent classification in *ENVI.*	Aerial Photography	Colour IR	Extensive sampling carried out in areas that were able to be accessed by foot	Classification process distinguished between *Ulva* spp. and *Ceramium* spp. successfully, but could not map biomass using colour IR imagery	Macroalgal distribution could be mapped in the Avon-Heathcote Estuary using this method

2.4.1 Aerial Photography

Environmental Remote Sensing Programme, Aberdeen University (1994)

In August 1994, the Ythan Estuary in Scotland was mapped using aerial photography by researchers from the Aberdeen University. The reason behind this was the requirement for a cost-effective, long-term method for mapping and monitoring algal weedmats. Previous ground surveys and aerial photography had not been successful at achieving this. A model aircraft was flown at 300-500 m to capture black and white, colour and infrared imagery. Ground-truthing was also carried out. 25 ground control points (GCPs) were captured using a *Trimble* GPS prior to the flight so that any image distortions could be corrected. The images produced were scanned and the tiles imported into ERDAS *Imagine*. This aerial photography differentiated between macroalgae, sand and mud flats. Visual enhancement techniques and tools improved interpretations of the imagery in addition to displaying combinations of colour and false colour imagery. This method has great potential for mapping macroalgae in the Avon-Heathcote Estuary because the macroalgae live amongst sandy and muddy sediments.

Guichard et al. (2000)

This macroalgae mapping method was tested on an intertidal rocky shore in May and October 1997. They aimed to show the usefulness of remote sensing for ecological studies. A remotely controlled blimp was used to capture colour and infrared aerial photography at a flying height of up to 80 m and a pixel resolution of 1 cm. Extensive ground-truthing was carried out immediately after aerial photography was taken. The quadrats were sampled at the same place as the GCPs and the quadrats were photographed for later viewing. Macroalgae biomass was determined with 73 % accuracy through the production of a Normalised Difference Vegetation Index (NDVI). A NDVI is a measure of vegetative cover based on near-infrared and visible measurements (National Aeronautics and Space Administration 2008) High resolution imagery, including infrared, could be useful for mapping biomass with reasonable precision in the Avon-Heathcote Estuary.

Clinton et al. (2001)

This research aimed to create a method for mapping eelgrass in the Yaquina Bay Estuary in the United States of America (USA). Though the focus was on eelgrass, macroalgae were identified using false colour infrared aerial photography, collected at low tide at a pixel resolution of 20 cm. A variety of water exposure levels and densities were visible. Of most interest, was the mixture of eelgrass versus macroalgae, each of which could be distinguished from the other based on colour ratios. Like Guichard et al. (2000), a NDVI was developed to classify eelgrass and macroalgae as well as non-vegetated areas, with approximately 70 % accuracy. Although the focus of this research was eelgrass, the NDVI could be useful for determining the extent of the macroalgae at the Avon-Heathcote Estuary.

Cole et al. (2002)

In this study an aircraft was used to map macroalgae in Rehoboth Bay, USA, in spring 1999. North to south flight paths were used. Because of the water depth, floating buoys were placed as GCPs and located using a GPS. Colour aerial photography was taken from the aircraft and only limited field surveys were carried out. The images were registered in ERDAS *Imagine* and were clipped to remove any effects caused by solar glare. The images were subsequently classified using both supervised (user-directed) and unsupervised (computer-directed) classifications. The classifications resulted in land and water in some instances, classified as macroalgae. The most successful submerged aquatic vegetation (SAV) classification was by visual identification on a computer. *Arcview* was used to identify and classify the macroalgae based on the visual interpretation of the clipped images. Figure 2.17 shows a mosaic of the Rehoboth Bay with macroalgae digitised. The spatial extent of macroalgae was determined in only the shallow parts of the bay, but as discussed in the following section, sea floor surveys provide a way of mapping the deeper parts of the bay.

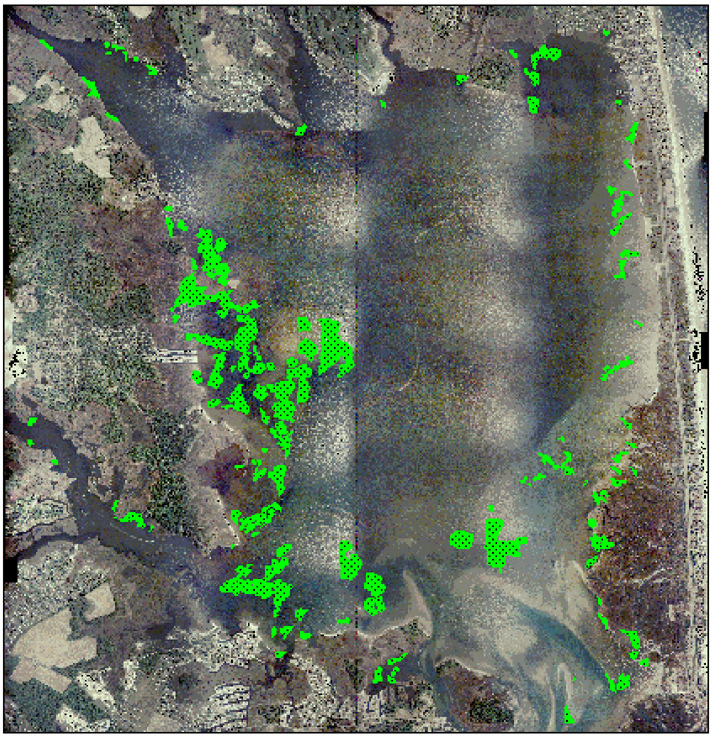


Figure 2.16 Mosaic of Rehoboth Bay showing macroalgae areas in green (Cole et al. 2002).

Green (2005)

Existing aerial photography of variable quality was used to map the macroalgae species of the Ythan Estuary Scotland, in 2004. The location and extent of weedmats was investigated so that temporal changes could be monitored. The project, which was completed in three weeks, provides a standardised approach for weedmat monitoring and mapping. The photography was from aircraft flown at a height of 300-500 m. The images were selected, scanned and geo-corrected for each set and then imported into a GIS and boundaries were digitised. The imagery that was available was from 1989, 1992, 1994 and 2000. No ground-truthing was possible. Like the aerial photography project carried out by the Environmental Remote Sensing Programme (1994), the project was successful at distinguishing macroalgae, but not individual species, because often the boundaries were gradual, but general annual macroalgal variations were observed. A detailed comparison between the existing Ythan Estuary and the Avon-Heathcote Estuary aerial photography is given in Chapter 3.

Nezlin et al. (2007)

Colour infrared aerial photography was trialled in Newport Bay Estuary in southern California in order to map the changes in the macroalgal distribution on an inter-annual and intra-annual basis. Aerial surveys were complimented by ground-based surveys of macroalgal coverage. Ground samples were taken for accuracy assessment. Resolution of imagery was 25 cm and was orthorectified and georegistered. Like Clinton et al. (2001), colour infrared photography was chosen due to its ability to enhance the contrast between vegetated and non-vegetated areas. The three main cover types were *Ulva* spp., *Ceramium* spp. and bare sediment. These were distinguished with high precision. It was found that areas of high cover were more accurately mapped than areas of algae with less than 75 % due to the inability of the imagery to resolve smaller percent cover values. This conclusion was also drawn by Clinton et al. (2001). Three images were created from data collected between July and October 2005. Each of three mosaic composite images were classified and it was found that *Ulva* spp. distribution significantly increased from July to October. This method was effective at mapping macroalgal coverage of more than two different genera of algae in areas of high cover.

2.4.2 Sea Floor Surveys

Riegl et al. (2005)

While sea floor surveys do not involve any aerial photography, it is important to understand the environments in which they can be used. An acoustic seafloor surveyor was used to map macroalgal biomass in the Indian River Lagoon in the USA. Three areas of the lagoon were monitored so that seasonal changes in the distribution of biomass of both macroalgae and seagrass could be observed. The surveys were carried out in 2002 and 2003. Extensive ground-truthing was carried out which included sampling and weighing of macroalgae and seagrass. The biomass was measured by counting the pixels assigned to classes and comparing that with what was measured in the field. The mapping project was successful at mapping biomass to an extent, because there was still some residual error between sparse and dense algae predictions and seasonal patterns. It was also found that algal biomass was a function of depth and season.

National Oceanic and Atmospheric Administration (2007)

Instead of using an aerial approach to mapping macroalgal cover, such as that by Cole et al. (2002), Delaware's Inland Bays were surveyed using a single beam acoustic sensor mounted to a boat by the Delaware Department of Natural Resources and Environmental Control and Delaware Coastal Programs. This was undertaken in spring 2000. The sensor works in water depths of 1 m to 1000 m and thus was ideal for mapping the shallow Delaware Bays. The mean water depth is 7 m (Donate et al. 2004). A series of transects recorded data as no algae or algae (Figure 2.18). The macroalgae have a large impact on the environmental health of the bays as well as on recreational users. When the algae die, it decays and depletes water of oxygen causing fish to suffocate and odours to drift onshore. Transects were surveyed along the sea floor, with the strength and time of the acoustic return measured to collect data. No ground-truthing was possible. The survey was highly successful due to the ability of the equipment to work in turbid waters. The aims of the surveys were to establish the location of the dense populations of algae and to understand how harvesting is affecting the population size and distribution. Very fast data processing could allow for efficient harvesting of the macroalgae. Because single beam acoustic sensors are effective in shallow water, they could be used to map the macroalgae of the Avon-Heathcote Estuary at mid to high tide. This method has only been used to map one macroalgae species, *U. lactuca.* There could also be an opportunity to map the channels of the estuary using this technique, particularly for *Gracilaria,* which has one third of its entire biomass living in the channels (Christchurch City Council 2000). Furthermore, there is potential for benthic surveying in the deeper waters of McCormacks Bay.

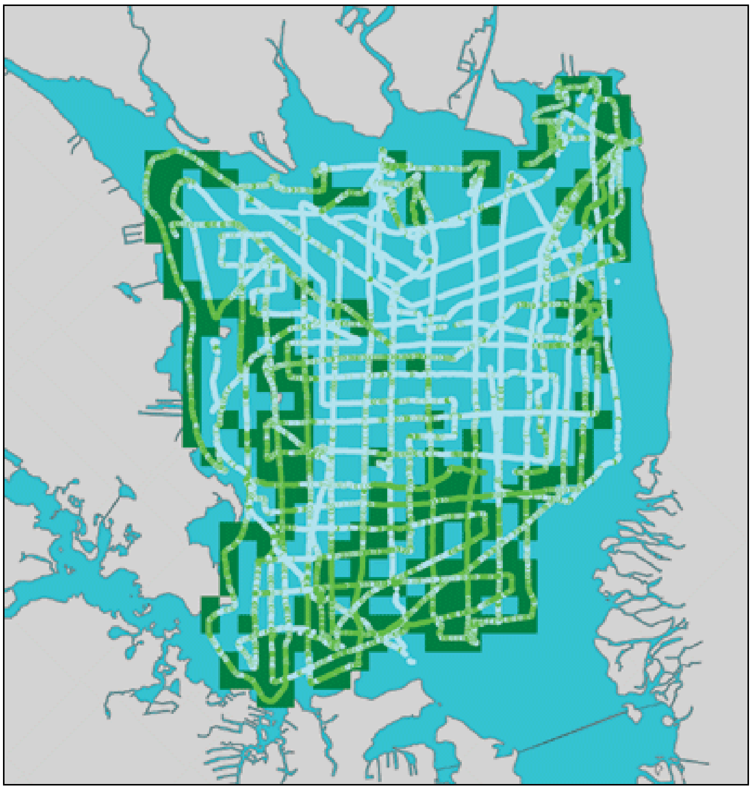


Figure 2.17 Transects where acoustic data points were collected (white) classified as algae (green) and no algae (blue) (National Oceanic and Atmospheric Administration 2007).

2.4.3 Summary of International Studies

The recent techniques that have been used internationally reflect the positive influence of technology in mapping macroalgae. The literature has focussed only on mapping macroalgal species as a single entity, rather than distinguishing between separate species. One exception to this was Green (2005), who attempted but could not distinguish between species of macroalgae effectively. Remote sensing techniques, such as using infrared imagery and creating a NDVI, are only effective for mapping macroalgae in areas free of surface water.

2.5 Key Macroalgae Mapping Reports

The following two reports present guidelines for mapping benthic communities. A brief overview of what is included in the documents is given for the purpose of providing background to the information that is set out in the reports.

Finkbeiner et al. (2001)

This report was produced with the main goal to provide guidance for mapping benthic habitats using aerial photography. Included in benthic habitats are macroalgal beds and drift algae accumulations which according to this report can be reliably mapped using aerial photography. This document recommends methods for crucial steps involved in capturing and interpreting aerial photography: image acquisition, collection of GCPs, image interpretation, data development, digitising habitat data, field surveys and ground-truthing, data validation, additional mapping technologies, data quality and documentation. All of these topics are discussed throughout the report broadly in terms of benthic mapping, but are applicable to a number of benthic environments. This report provides a basis from which to develop a suitable method to achieve the fourth objective of developing a methodology to map macroalgae in the Avon-Heathcote Estuary using high resolution imagery.

Robertson et al. (2002)

This report was prepared for Councils and the Ministry of the Environment in New Zealand. The report contains three parts. Part A outlines the development of the Estuary Monitoring Protocol (EMP). The rationale behind the document is outlined along with the characteristics of New Zealand estuaries. The use of GIS in broad-scale habitat mapping and fine-scale environmental monitoring was discussed. Part B is appendices to Part A. The appendices outline the characteristics of case study estuaries as well as broad-scale mapping characteristics and details of fine-scale monitoring. Part C is a guide for the application of the EMP, based on Part A and Part B. This report suggests protocol which should be followed when carrying out environmental science-related field work in New Zealand estuaries which is, like Finkbeiner et al. (2001), useful for developing a high resolution-based methodology for mapping macroalgae in the Avon-Heathcote Estuary.

2.6 Conclusion

As remote sensing technology improves, there are a new range of techniques available to map macroalgae in estuarine environments. While ground-based surveys of macroalgae in the Avon-Heathcote Estuary have provided an understanding of the extent of species of macroalgae dating back over fifty years, techniques to map macroalgal cover using remote sensing methods are more efficient and effective (Guichard et al. 2000; Cole et al. 2002; Nezlin et al. 2007). There has only been limited success, however, in mapping biomass using data from the infrared and visible spectrums (Guichard et al. 2000; Green 2005; Nezlin et al. 2007).

Chapter 3: Review of past Aerial Photography and Satellite Imagery used to Map Macroalgae in the Avon-Heathcote Estuary

3.1 Introduction

Recent attempts to map the macroalgal cover in the Avon-Heathcote Estuary have utilised remote sensing methods rather than ground based surveys in the estuary as discussed in Chapter 2. Methods used include using satellite imagery and aerial photography to map cover of macroalgae. Evaluation of satellite imagery and aerial photography shows that while potential exists for both, aerial photography is more promising due to the ability of the data to be captured and output at a higher resolution than satellite imagery.

3.2 Evaluation of the Success of Satellite Imagery Mapping

Landsat 5

An image taken of the Avon-Heathcote on December 23, 1990, was taken by Landsat 5 (Figure 3.1). Satellite classification from 1990 carried out by Landcare Research used multispectral data in the visible blue, visible green, visible red, near infrared, mid infrared and thermal infrared spectral bands. These have a spatial resolution of 30 m except the thermal band which is 120 m. Pixel sampling was converted to 10 m to render the same spacing as the 2002 satellite image classification. No ground-truthing was able to be done. The imagery enabled the mapping of features using a supervised classification. These features include seawater, oxidation ponds, land vegetation, buildings/bare ground/beach, shallow water and, of most interest to this research, some marine vegetation and marine vegetation on mud. Evidently the species of marine vegetation were not able to be distinguished from each other, which pose a problem when mapping different macroalgal species. The terms ‘some marine vegetation’ and ‘marine vegetation on mud’ are broad terms which hold no value without knowledge of what the marine vegetation refers to. Because individual marine vegetation species cannot be distinguished, the use of satellite imagery to classify the images is not ideal.

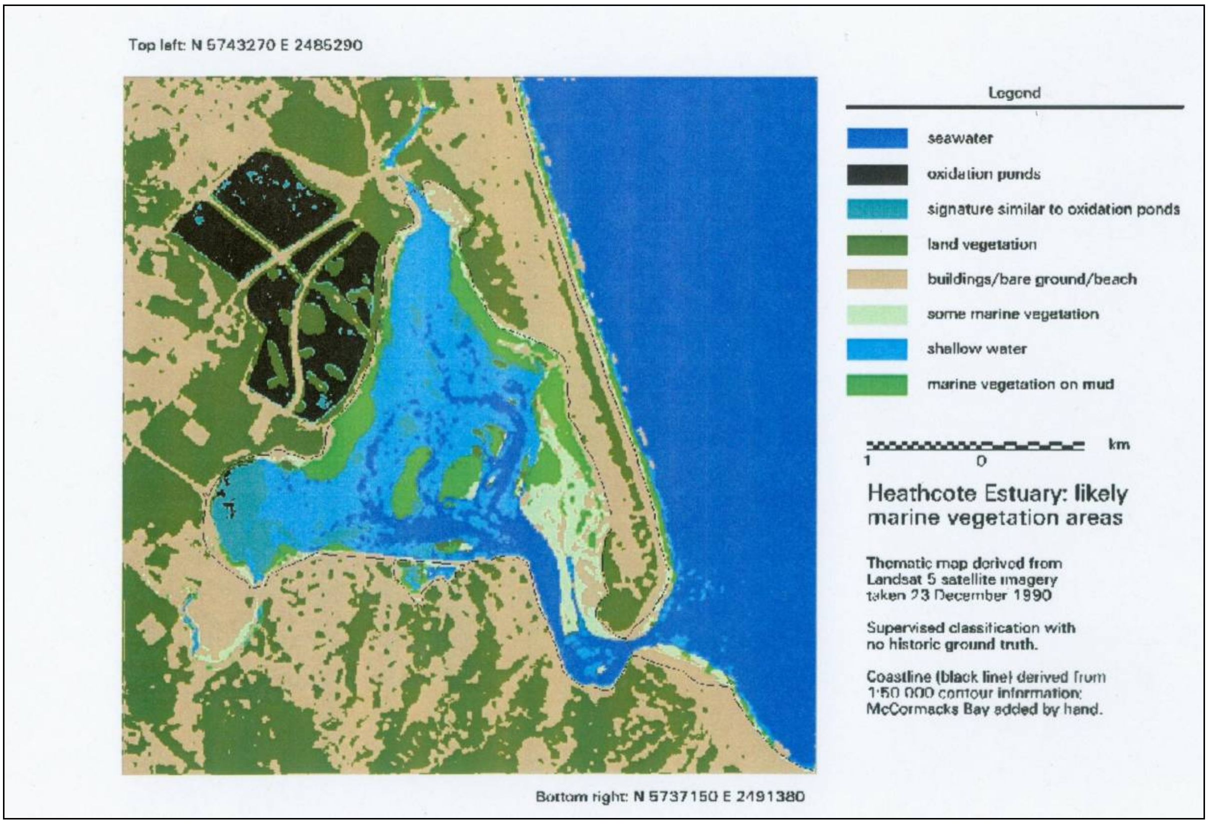


Figure 3.1 Likely marine vegetation areas (Data sourced from Landcare Research 1990).

SPOT-4

Figure 3.2 shows a classified image of the Avon-Heathcote Estuary taken on March 14, 2002. This classification has a resolution of 10 m ground cover per pixel. Compared to the 1990 satellite classification, the classification of this image by Landcare Research has distinguished *Ulva* and *Gracilaria* separately, although seagrass was mapped in a mixed category with *Ulva*. *Ulva* and seagrass were mapped together, either because different spectral signatures were not observed and/or there was not any ground-truthing data (Stella Belliss, Scientist, Landcare Research, *pers. comm.* 2007).

Studies conducted on the spatial extent of seagrass in 2004 and 2007 by the University of Canterbury, determined that seagrass is located on the eastern side of estuary adjacent to the New Brighton Spit, with the *Ulva* mainly around Sandy Point and Discharge Point. This can only be concluded by carrying out ground-truthing which was not carried out for the classification. The reliability of the satellite imagery is questionable as indicated in the title, which refers to 'likely Seagrass, Ulva, and Gracilaria areas'. For the mapping of macroalgae and monitoring future changes, there is a requirement for better precision than just 'likely' areas.

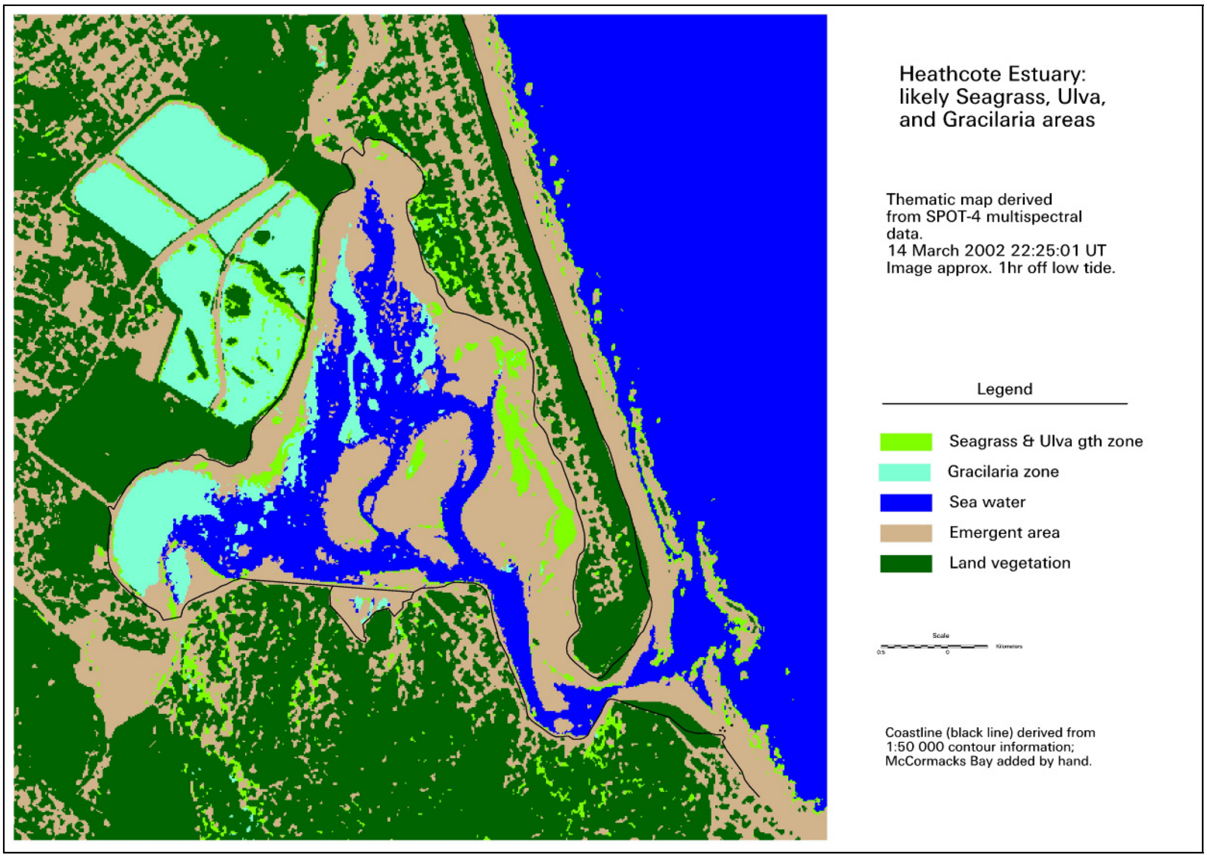


Figure 3.2 Likely Seagrass, *Ulva* and *Gracilaria* areas (Landcare Research 2002).

3.3 Evaluation of the Success of Aerial Photography Mapping

Robertson et al. (2002)

In their 2002 mapping exercise, Robertson et al. (2002) used aerial photography at 50 cm resolution taken by the Canterbury Regional Council on January 9, 2000. *Ulva, G. chilensis* and other features such as water and sediment types were digitally added to the photograph. These digitised areas were based on broad-scale surveys of intertidal habitats in the Avon-Heathcote Estuary (Robertson et al. 2002). Ground-truthing was not carried out on the day of the flights, which can inevitably lead to error in mapping features.

From this study, two film types were available in the present study to assess the imagery: black and white, and colour. The black and white imagery (of three combined bands) shows tonal variations in different features. From the imagery it is straightforward to distinguish between the water channels of the estuary and the sediment/macroalgae/seagrass cover. However tonal variations are not substantial enough to differentiate between *Ulva* and *G. chilensis*. The colour imagery is more useful for interpretation than black and white imagery because the sediment colour is clearly different from macroalgal cover. Figure 3.3 shows a comparison between the digitised image and the original image respectively. *G. chilensis* and the substrate are often difficult to distinguish because the colourations are often similar. The digitised image shows dark purple/brown colours as *G. chilensis*, while *Ulva* shows up as a green-blue colour. This seems realistic, as in situ *G. chilensis* appears red/brown and *Ulva* bright green. However, this classification does not take into account the high percentage of both *Ulva* and *G. chilensis* that occur today and were likely to occur when this image was taken in 2000 around Humphreys Drive.

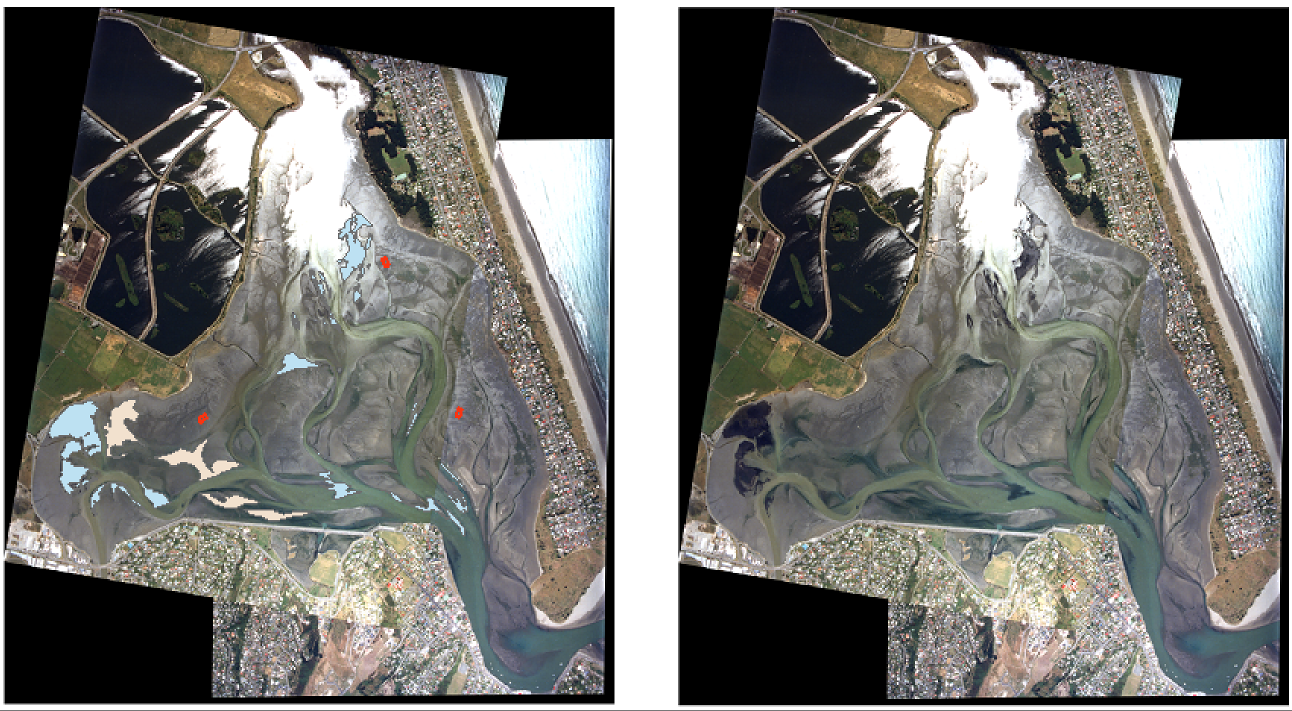


Figure 3.3 Comparison between digitised aerial photographic image (left) and original image (right) (Data sourced from Robertson et al. 2002). Note *Ulva* sp. is pale orange and *G. chilensis* is sky blue.

ECAN Imagery

ECAN has a selection of aerial photographic tiles available of Christchurch, including the Avon-Heathcote Estuary, with a 75 cm resolution, which corresponds to a flying height of approximately 10000 ft. The images are not helpful because they are not taken at low tide, which is necessary to map macroalgae effectively (Figure 3.4). In 2004, the dataset of aerial photographs from ECAN were examined. *Gracilaria* was able to be identified because of its dark red/brown colour, but the identification of *Ulva* was harder. This is the same problem with the imagery from Robertson et al. (2002). As a result of the poor definition of *Ulva,* ECAN did not continue with this monitoring programme.

Figure 3.4 Aerial photograph of Humphreys Drive and Sandy Point (Environment Canterbury 2007).

Blimp Aerial Photography

Blimp aerial photography was taken twice a year for the CCC, about every six months in approximately the same locations to show the changes in macroalgal cover. The helium filled blimp had a remotely controlled camera system (Skyworks International Limited 2007). Photographs were taken obliquely (Figure 3.5). These photographs were effective at gaining a general view of macroalgae cover. While cost effective at between \$300 and \$450 this programme was discontinued because the company that previously carried out the work was sold (Ken Couling, Senior Planning Engineer, CCC, *pers. comm.* 2008).

Figure 3.5 Typical blimp aerial photography carried out in January 2006 (Christchurch City Council 2006).

3.3.1 Mapping Macroalgae using existing Aerial Photography: the Ythan Estuary

The most relevant piece of previous research regarding the mapping of macroalgae using existing aerial photography comes from Green (2005). As previously mentioned, Green (2005) attempted to map the weedmats of the Ythan Estuary. While Green (2005) was able to map the weedmats, the separation of the individual macroalgal species was not possible. This is the problem that is encountered with existing aerial photography of the Avon-Heathcote Estuary. The comparisons are further similar in that distinguishing the sediments from macroalgae was possible. It was concluded from aerial photography of the Ythan Estuary that there is no possible way of determining biomass from aerial photography alone. Green (2005) further noted that field work would be required do distinguish the weedmats densities.

3.4 Conclusions

The macroalgal mapping techniques discussed above illustrate the potential of aerial photography more so than satellite imagery in mapping macroalgae of the Avon-Heathcote Estuary. This is because satellite imagery is limited in mapping macroalgae by its low resolution, the inability to separate individual species in classification, and the reliance on suitable atmospheric conditions. While aerial photography has similar problems with suitable atmospheric conditions and classification of individual species, the resolution can be substantially higher compared with satellite imagery. The map produced by Robertson et al. (2002) illustrates the potential of high resolution imagery for mapping macroalgae. Substantial ground-truthing carried out within the same day as the aerial photography is captured is necessary for reliable mapping of macroalgae.

Chapter 4: Development and Field Trial of Macroalgal Mapping Methodology

4.1 Introduction

The purpose of this chapter is to outline the methodology used in a field trial which establishes a suitable method to map the Avon-Heathcote Estuary macroalgae coverage and biomass using aerial photography and biological sampling respectively. The trial was carried out in the western most section of the estuary which is approximately 1 km² (Figure 4.1).

Figure 4.1 Map of Avon-Heathcote Estuary with the field area outlined in red (Adapted from Google Earth 2008).

4.2 Outline and Trial of Methodology

4.2.1 Tidal Considerations

Cole et al. (2002), Finkbeiner et al. (2001), Robertson et al. (2002) and Nezlin et al. (2007), all suggest fieldwork must be completed at low tide. Cole et al. (2002) elaborated further by recommending carrying out fieldwork within two hours before and after low tide depending on the nature of the intertidal environment. January 23 was decided on in the months leading up to the fieldwork because of the presence of a spring tide, which yields slightly more time to carry out fieldwork. Predicted low tide for Lyttelton was 11:45 am (National Institute of Water and Atmospheric Research 2008), which was at a time when the influence of the sun's glare was minimal.

Typically, there is an hour to an hour and a half delay of low tide from what is predicted at Lyttelton. This is further increased by approximately twenty minutes on the western side of the estuary when the wind direction is from the east. The recommendation by Finkbeiner et al. (2002) of planning to survey areas first exposed by the receding tide was particularly important for planning the routes to measure the location of GCPs and the ground-based biological survey.

4.2.2 Planning and Communication between Participants

Numerous people (eleven in total) were involved with fieldwork related to the methodology trial. Finkbeiner et al. (2001) recognised that careful planning is the key to the success of projects where numerous assistants are required. In the weeks preceding the methodology trial, meetings were organised to confirm the roles of each participant and provision of equipment (Table 4.1).

Table 4.1 Equipment used in fieldwork and providers

Geospatial Research Centre (GRC)	Doug Anderson	Geography Department	Biology Department	Additional Equipment
• *Canon EOS 400D* camera with a *Canon EF* 28 mm f/28 lens • Airborne navigation equipment including: • *NovAtel Synchronized Position Attitude and Navigation (SPAN)* • *NovAtel FSAS iMAR Inertial Measurement Unit (IMU)* • *Crossbow 440 IMU* • *NovAtel Superstar II* GPS receiver • *uBlox Antaris 4* GPS receiver	• microlight	• *Trimble R8 Global Navigation Satellite System* • Waders for people carrying out fieldwork in the estuary • Walkie talkies • *Ohaus* electronic balance	• Plastic bags for sample collection • 0.25 m² quadrat for sampling • Oven for drying samples in the laboratory • Laboratory scale	• Waterproof notebook • 1 m by 4 m of bright yellow fabric (cotton) • Pens, pencils and vivids • Bucket for the field scales • Aerial photographs

4.2.3 Weather Considerations

The predictions of a cloudy morning with a strong easterly breeze eventuated for January 23. According to Finkbeiner et al. (2001), Robertson et al. (2002) and Nezlin et al. (2007), aerial photography would ideally be carried out in low winds and on a sunny day. The final decision for flight of the microlight was the decision of the pilot. As recommended by Finkbeiner, Stevenson and Seaman (2001), in the days leading up to the fieldwork, numerous websites were viewed to attain a good indication of the weather (Elders Rural Holdings Limited 2008; Met Service 2008; The Weather Channel 2008). In addition, cloud conditions were consulted early morning of the fieldwork day to check for the height of broken cloud cover (Airservices Australia 2008).

4.2.4 Aerial Photography

In previous studies by Guichard et al. (2000) and Cole et al. (2002), GCPs have been used to geocorrect the imagery. In this fieldwork, they were used to determine how much error was involved with the corrections made based on the navigation equipment on board the microlight. In order to measure the coordinates of the GCPs a base station was set up (Figure 4.2) using an Order 2 Station, situated at the western end of Tern Street (Land Information New Zealand 2007). This base station was chosen because of its high 3 mm accuracy. The system used was the *Trimble R8 Global Navigation Satellite System* (Figure 4.3). Coordinates used were set to the local Mt. Pleasant Local Circuit 2000 coordinate system.

GCP measurements began half an hour off predicted Lyttelton low tide. Yellow fabric markers were submerged in any existing water to ensure that the position stayed fixed and were measured as topo points (Figure 4.3). The real-time kinematic navigation technique was used in capturing the locations of the GCPs. Accuracy was increased by locking on to 10 to 15 satellites from the USA's GPS satellites and Russia's Global Navigation Satellite System. 32 markers were able to be measured (Appendix 1) including fixed buoys.

Figure 4.2 Base station and receiver on Tern Street (photograph M. Brosnan 2008).

Figure 4.3 Geography Department Workshop technician Nick Key and field assistant Bree Sowman capture a GCP using the *Trimble R8 Global Navigation Satellite System* (photograph M. Brosnan 2008).

Aerial photography was captured by flying an *AirBorne* Trike (commonly referred to as a microlight) over the field area (Figure 4.4). The microlight was a variation on the blimp and small aircraft used to take imagery by Guichard et al. (2000) and Cole et al. (2002) respectively. Doug Anderson, the pilot, based the aircraft out of a paddock on Breezes Road, opposite the Water Treatment Ponds. This was in close proximity to the field location (about 1 km), which was ideal for the fieldwork insofar as it reduced the time travelled to the field area and controlled the time that the flights would occur more precisely.

Figure 4.4 Close-up of the *AirBorne* Trike XTS 912 (photograph D. Anderson 2007).

Two test flights were carried out on the day of the flight to check that the equipment was functioning correctly and to indicate the field area to the pilot. Six flight paths were flown in an east to west direction, with the survey beginning in the northern most part of the field area. The flight was carried out at low tide at 1000 ft, although additional sections of the field area were captured at 500 ft and 2000 ft. At 1000 ft the resolution of imagery was 10 m. At 1000 ft the coverage of each image was approximately 258 m along-track by 172 m cross-track. All imagery was taken using the visible spectrum. The camera used was a *Canon EOS 400D* and was set to IS0 200 and aperture priority mode. The images were stored on the camera as high resolution, full-size joint photographic experts groups (JPEGs). The pilot had control of a time-lapse trigger box, which allowed the camera to take images at one second intervals. Overlap of 60 % at the ends and 30 % at the sides was recommended by Cole et al. (2002), but coverage for the final three tracks did not have any overlap on the sides. Because the camera took images at short intervals there was approximately 90 % overlap at the ends.

An airborne navigation system was mounted onto the microlight so that information could be collected about its latitude, longitude, altitude, and northern and eastern velocity as well as the GPS time. The *NovAtel SPAN* failed to operate successfully due to misconfiguration, so it did not record any data. The attitude information was therefore collected using records from the *uBlox Antaris 4* GPS receiver and the *Crossbow 440 IMU.* The *440 IMU* was the secondary attitude sensor. In addition to the sensors, a *NovAtel Superstar II* and a *uBlox Antaris 4* GPS receiver were used.

4.2.5 Ground-based Biological Sampling

Ground-truthing was carried out in two and a half hours, half and hour before low tide and was completed two hours after low tide. Biological sampling was undertaken at eight predetermined survey sites that were 200 m² (Figure 4.5). The surveying began outside the Mount Pleasant Yacht Club and continued along Humphreys Drive and finished at Sandy Point. It was hoped that the survey sites would be marked out by the GCPs placed out earlier, however, the actual sites sampled were approximately 20 to 30 m closer to the estuary periphery because the water was too deep to safely sample areas close to the Heathcote Channel.

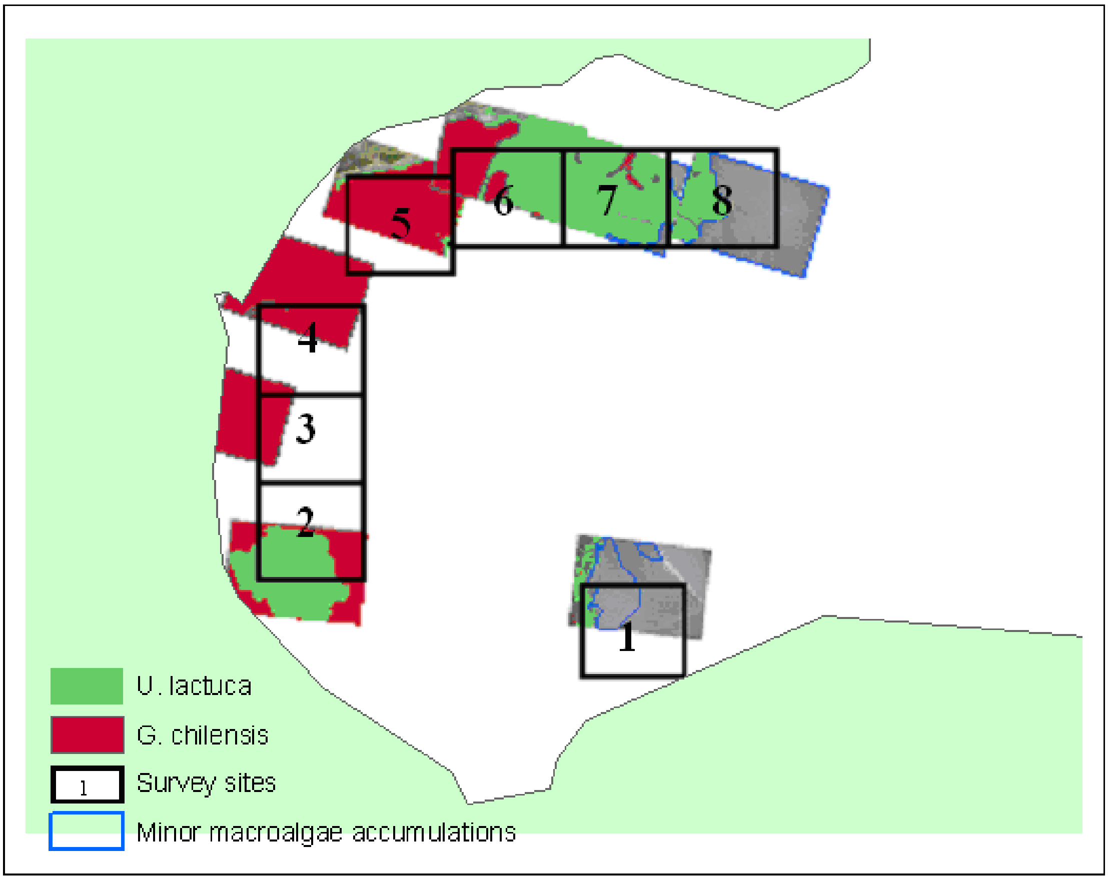


Figure 4.5 Survey sites used for biological sampling.

Biological sampling steps used in the field:

1. Located corners of the survey site by estimation using GCPs and if necessary used landmarks in the water and on land.
2. Sketched a map of the survey site showing broad macroalgae and/or sediment cover.
3. On the basis of (2), it was decided to randomly sample or randomly stratify the sample at the survey site. (Random stratified sampling only took place if there was more than one distinct cover type, i.e. macroalgae and bare sediment. This was then divided into categories (a) and (b).)
4. Walked 20 to 30 paces towards the centre of the survey site.
5. Threw a 0.25 m² quadrat behind the head.
6. Estimated percent cover of macroalgal species within the quadrat and within a 5 m radius.
7. Determined whether macroalgae is attached or unattached to sediment.
8. Collected all algae present within quadrat and rinsed well in hands to reduce amount of water in sample.
9. Measured wet weight using *Ohaus* electronic balance placed inside a bucket.
10. Placed sample in plastic bag (first three samples only).
11. Walked at 90° to the previous quadrat sampled for 20 to 30 paces five more times and repeated steps 5-10.
12. Repeated steps 1-11 for each survey site.

Steps used in laboratory analysis of biological samples:

1. Cut tin foil into a size that is large enough to enclose the sample.
2. Weighed the tin foil.
3. Rinsed any mud off the samples using half a bucket of sea water and fresh water combined.
4. Separated sample into the macroalgal species present.
5. Placed the various individual samples in tin foil.
6. Weighed wet weight using laboratory scales.
7. Marked the number of the sample on the outside of the tin foil using a vivid.
8. Placed in tray.
9. Repeated process for all survey site samples.
10. Placed tray of samples in oven at 65°C until dry (approximately 180 hours).
11. Weighed largest sample of *U. lactuca* and *G. chilensis* in scales separately and repeated this from 5 days onwards to monitor any change in weight. (When constant weight over successive days was achieved, all the samples were weighed for dry weight.)
12. Weighed all samples individually.

4.2.6 Image Processing

Initial image processing to georeference images was carried out by personnel from the GRC. The raw data was run in *POINT* software. This combines the GPS data from the *uBlox Antaris 4* and inertial data from the *Crossbow 440 IMU* to render estimations of the platform location and orientation over the time of the flight. Because the *NovAtel SPAN* failed to operate successfully, the less accurate, secondary navigation system was used. The maximum error of the imagery was 40 m on the ground. This issue is not concerning because there was no attempt to correlate point locations on the ground with points on the aerial photography. The images were georeferenced individually and no attempt was made to create a mosaicked image. Because the estuary is relatively flat, a constant elevation was assumed. Images were output as geo Tagged Image File Formats (TIFFs).

4.2.7 Image Analysis and Classification

High resolution geoTIFFs were initially viewed to obtain a general idea of data quality. Eight images were then selected based on their location in relation to the eight biological survey sites (Figure 4.5). The purpose of this is to give an indication of the coverage of macroalgae at the sampling sites. It must be stressed that the images do not completely coincide with the survey sites due to the coverage of the images. The macroalgal species were digitised using tools available in *ArcMap*. This was the technique used by Roberston et al. (2002) for mapping features in selected New Zealand estuaries. The areas were mapped on the computer screen and were saved as GIS layers as recommended by Robertson et al. (2002).

The general recommendations of Finkbeiner et al. (2001) for interpretation decisions were used. The recommendations included: (1) focussing on mapping outer boundaries of beds rather than internal structure, (2) including areas of small macroalgae patches rather than excluding them and mapping this low percentage cover as a singular entity and (3) designating a minimum detection unit and a minimum mapping unit. For the digitised images taken at 1000 ft (Figure 4.5), these are 20 cm and 1.5 m respectively. For example algae which are less than 1.5 m in diameter were mapped as minor macroalgal accumulations. Visual evaluation of the imagery using fundamental image interpretation elements, such as colour, tone, texture, contrast and association, as recommended by Finkbeiner et al. (2001) was carried out using the *Environment for Visualising Images (ENVI)* 4.3 software package (ITT Corporation 2007; Nezlin et al. 2007). Only colour and tones proved useful in adequately identifying macroalgal cover, channels and sediment.

Like the research by Cole et al. (2002), unsupervised and supervised classifications were carried out. Unsupervised classification is entirely computer directed whereas supervised classification is user directed (Lilliesand and Kiefer 2000). In unsupervised classification, classes are based on natural groupings present in the image spectral values, compared with supervised classification which involves identifying representative training areas and then classifying each pixel into different cover types after areas have been trained (Lilliesand and Kiefer 2000). In this analysis, unsupervised classification was carried out by using the isodata classification which is an iterative approach, whereby cluster means are iterated until a defined threshold is reached (Driggers 2003). Supervised classification was carried out using the maximum likelihood classification, whereby each class is modelled with a separate distribution and each pixel is classed based on the highest probability of generating that pixel (Wilson and Gallant 2000). Classifications were carried out in *ENVI* for single high resolution geoTIFFs and for the low resolution overview map of 460 images of the field area which were taken at 1000 ft. Classifications were based on red blue green (RGB) colour.

Supervised and unsupervised classifications were run for the overview map of the field area (Figure 4.6). This was done firstly viewing a selection of high resolution images across the field area to obtain a general idea of the distribution of the macroalgae, which was combined with knowledge of the areas through ground-truthing and this was applied to map overall macroalgal coverage. In situations where distinguishing between cover types was difficult, chiefly in areas that were unobtainable by ground-truthing, they were examined again on the high resolution imagery to confirm the overall distribution. This knowledge was then applied to the low resolution image classification.

While a complete set of image interpretation was carried out with images taken at 1000 ft, some of the imagery taken at 500 ft and 2000 ft was compared in order to view the benefits of the change in resolution and image coverage. At 500 ft the resolution was approximately 5 cm and coverage of each image was 129 m along-track and 86 m cross-track. At 2000 ft the resolution was approximately 17 cm and coverage of each image was 517 m along-track and 344 m cross-track. Supervised classification was carried out for both the images.

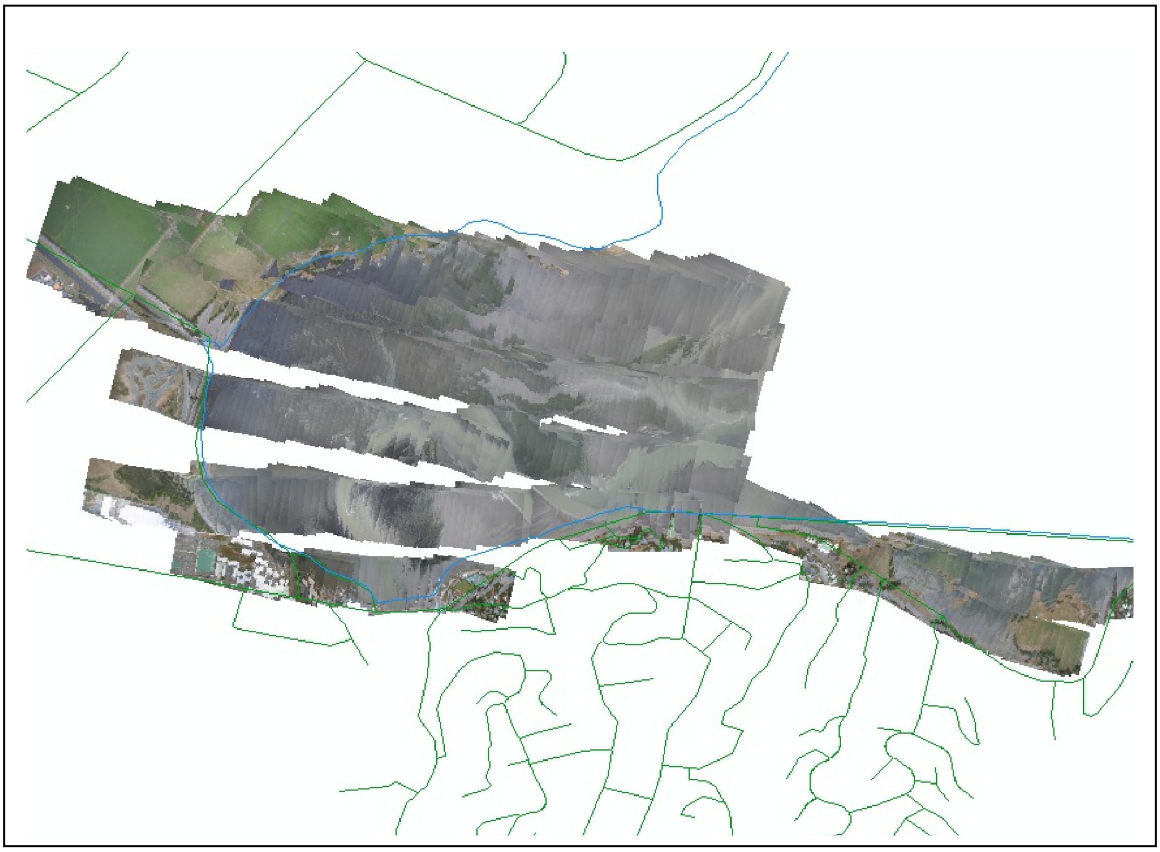


Figure 4.6 Low resolution overview map of all images taken from 1000 ft at low tide with a high sun angle.

4.3 Results

4.3.1 Image Interpretation

When interpreting the results it is important to note that the macroalgal cover shown is the canopy surface cover since there is no indication, of what is beneath the canopy surface. The classification scheme used in the following figures refers to dominant cover, however, there is often *G. chilensis* under *U. lactuca* in the field location. It should also be noted that there was no presence of *Enteromorpha* in the field area when the fieldwork was carried out.

Unsupervised classification of the single geoTIFF distinguishes between the algae species (Figure 4.7). Figure 4.8 shows that this was the case for the supervised classification as well. The unsupervised classification was not as useful as the supervised classification because it did not show the minor macroalgal accumulations and sediment cover was divided into three different classes due to their different spectral properties. Figure 4.9 is the geoTIFF digitised in *ArcMap*, which is displayed for the purpose of comparing the results between the classified images and the digitised image. The digitised geoTIFF shows very similar results to the classification in terms of identifying macroalgal cover.

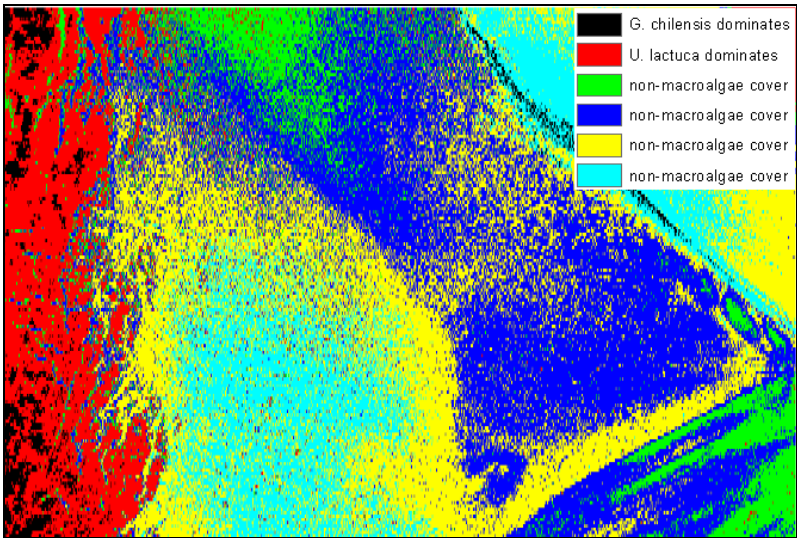


Figure 4.7 Unsupervised classification over approximate area of survey site 1.

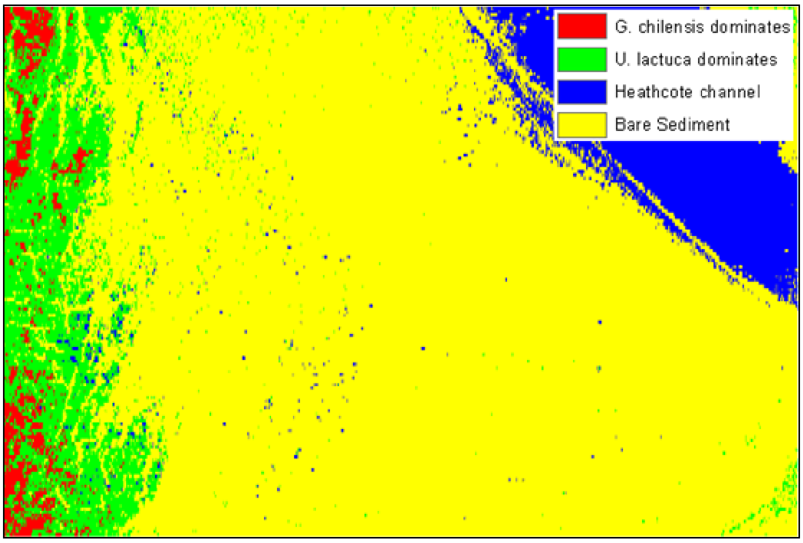


Figure 4.8 Supervised classification over approximate area of survey site 1.

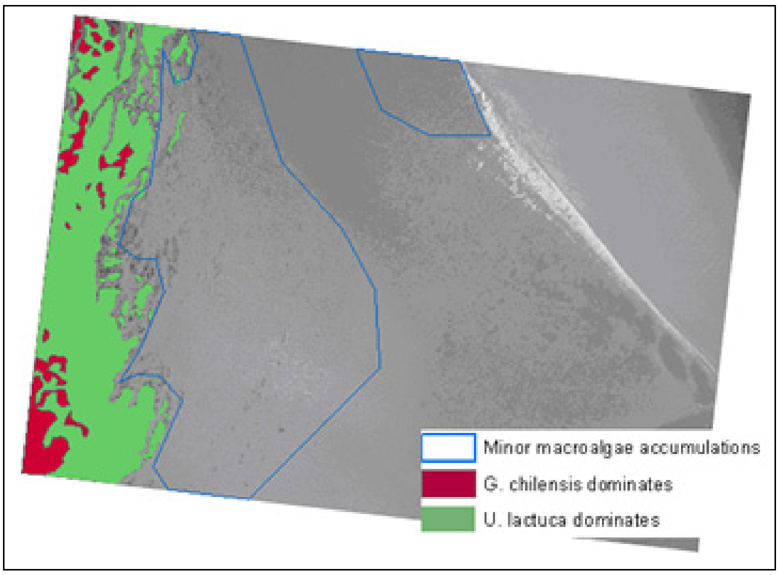


Figure 4.9 High resolution image over approximate area of survey site 1.

Unsupervised classification of the overview map resulted in mapping the macroalgae as a singular entity (Figure 4.10) which was not the case for the single geoTIFF outlined above. Supervised classification yielded realistic results that reflected field observations (Figure 4.11). Figure 4.11 shows that there was high percentage cover of *G. chilensis* along Humphreys Drive, as well as opposite the Mount Pleasant Yacht Club. *U. lactuca* cover was particularly high west of Sandy Point and extended south to the Heathcote Channel. There were large areas of bare sediment at Sandy Point as well as to the north east of the Mount Pleasant Yacht Club. Because the data was low resolution minor macroalgal accumulations (most of which was *U. lactuca*) could not be distinguished in the supervised classification. Through substantial ground-truthing it was evident that the supervised classification was the most accurate way of mapping macroalgal coverage. Furthermore it was less labour intensive than mapping surface covers in *ArcMap* (Robertson et al. 2002).

Supervised classification of an image taken at 500 ft near the windsurfing car park gives an accurate classification of both macroalgal species (Figure 4.12). The image taken at 2000 ft, slightly to the east of the image taken at 500 ft yielded an accurate classification as well (Figure 4.13). When analysing the colour imagery in *ENVI* and *ArcMap*, it could be seen by the imagery taken at 500 ft that features could be distinguished more accurately compared with the 1000 ft and 2000 ft imagery, but the resolution at 2000 ft is still high enough to distinguish between macroalgal species. Increased flying height is advantageous because it reduces flying time required to capture data, file size and processing time.

McCormacks Bay was not part of the field area but aerial photography was taken of the area. From the supervised classification of the low resolution overview map (Figure 4.11), it appeared that there was significant *U. lactuca* and *G. chilensis*, but with no ground-truthing carried out no further comment about macroalgal coverage or biomass will be made. There does, however, appear to be considerable potential for mapping coverage of macroalgae in McCormacks Bay using this method.

4.3.2 Ground-based Biological Sampling

Before the results could be analysed it was first important to display data in the statistical package Statistical Analysis System (SAS, Statistical Analysis System Institute 2008) to test for the assumptions of the F-test used in Analysis of Variance (ANOVA) tests. ANOVA tests were used to test for variability among sites as recommended by Robertson et al. (2002). For each data set the following plots were viewed: (1) histogram of residuals to check for no outlying residuals and normal shape, (2) residuals against predicted variables to check for constant spread, and (3) normal probability plots to check for skewness. In most instances, these assumptions hold adequately to perform an F-Test even though n is small. A few outliers (one or two) are present, however the most important assumption of homoscedasicity holds well for all datasets for effects observed across the surveyed sites. All the data sets have some minor to moderate skew, but they are adequately normal to perform an F-Test. It should be noted that sampling at survey site 8 was stratified and, thus, was not included in the statistical analysis.

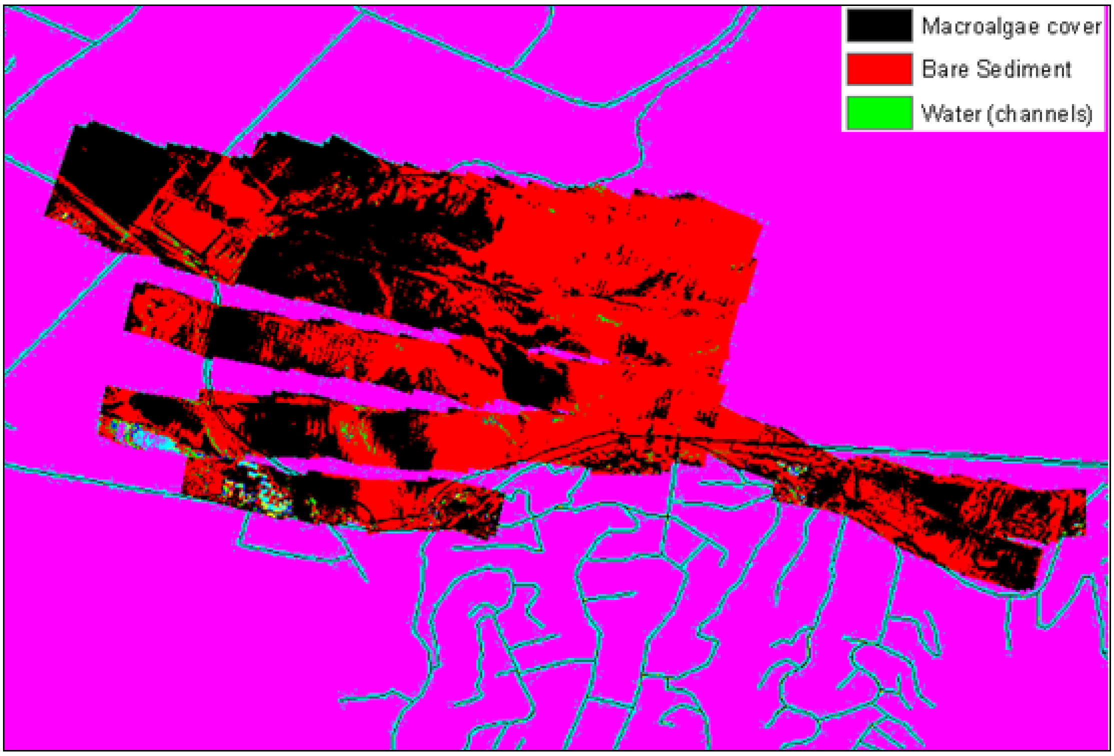


Figure 4.10 Unsupervised classification of low resolution overview map taken at 1000 ft.

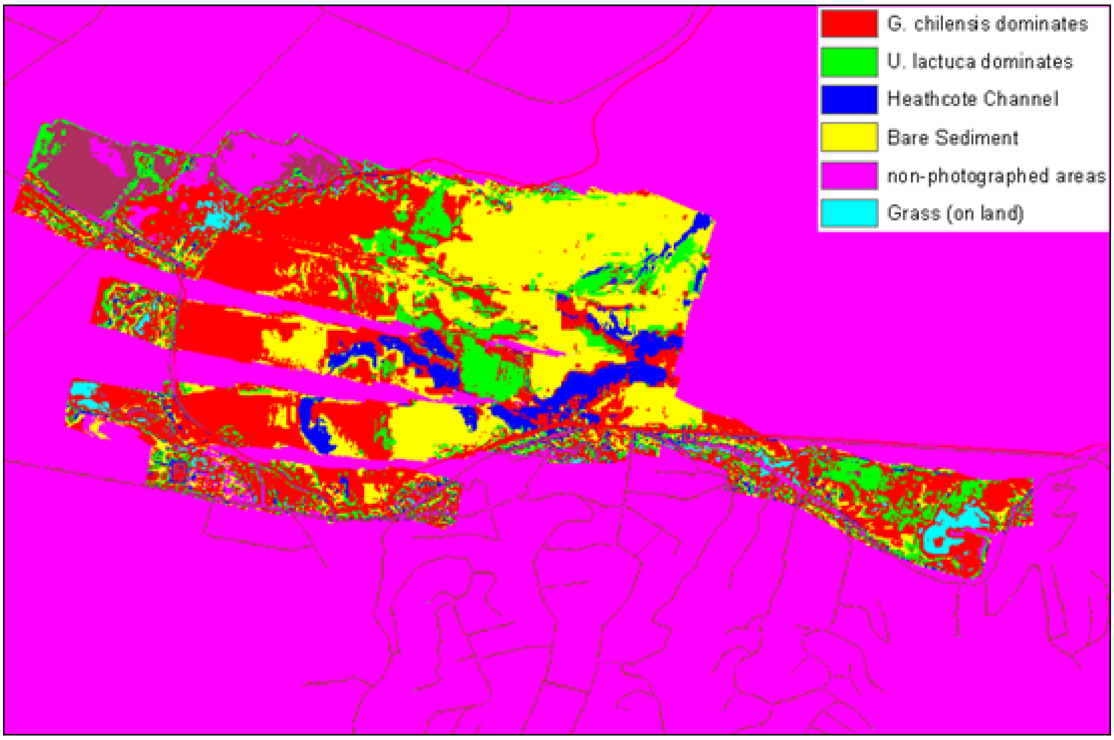


Figure 4.11 Supervised classification of low resolution overview map taken at 1000 ft.

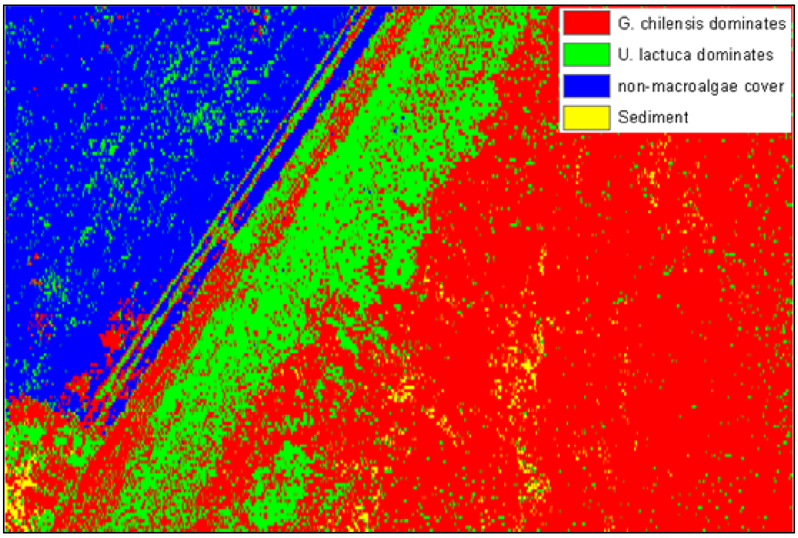


Figure 4.12 Supervised classification of single image taken at 500 ft near the windsurfing area.

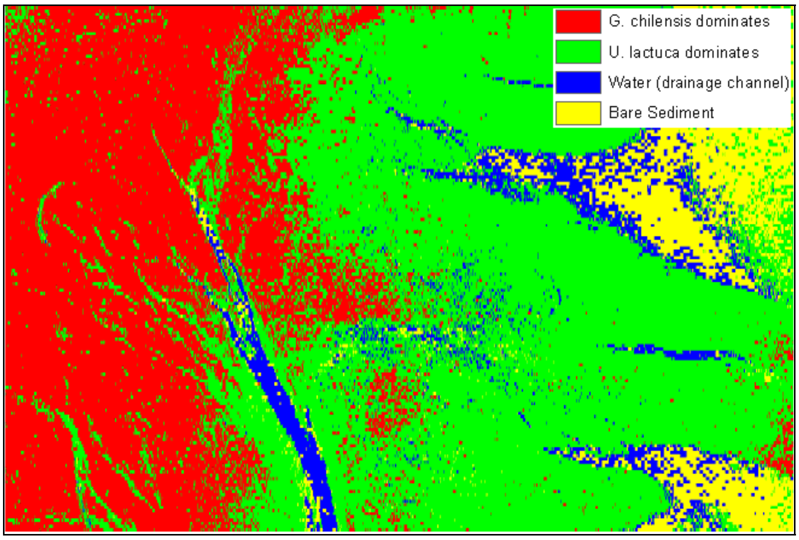


Figure 4.13 Supervised classification of single image taken at 2000 ft near the windsurfing area.

Figures 4.14 and 4.15 show wet weight biomass of *U. lactuca* and *G. chilensis* measured using a 0.25 m^2 quadrat in the field. Analysis reveals high total biomass in sites 2-7 as well as high variation in biomass within sites. *G. chilensis* has substantially higher biomass at sites 6 and 7. There was negligible *U. lactuca* and *G. chilensis* biomass at sites 1 and 8b, but there was very high *U. lactuca* biomass at site 8a. Variation within sites for *U. lactuca* was insignificant (Two-Factor ANOVA without replication; $F=0.92$, $df=5$, $p=0.48$) and between sites the differences were significant ($F=2.43$, $df=6$, $p<0.05$). Variation within sites for *G. chilensis* was also insignificant (Two-Factor ANOVA without replication; $F=0.91$, $df=6$, $p=0.49$). Variation between sites was highly significant (Two-Factor ANOVA with replication; $F=4.91$, $df=6$, $p<0.001$). It should be noted that the same conclusions can be drawn by using only the first three samples of each survey site.

Wet weight biomass of *U. lactuca* and *G. chilensis* measured in the laboratory are shown in Figures 4.16 and 4.19. There was very similar biomass of *U. lactuca* and *G. chilensis* at sites 1, 2, 3 and 4, but there was a substantial increase in *G. chilensis* at sites 5, 6 and 7, while *U. lactuca* decreased in biomass over those sites. There was very high biomass of *U. lactuca* at site 8a. There were insignificant differences between sites for *U. lactuca* (Two-Factor ANOVA without replication; F=1.08, df=6, p=0.42) and within sites (F=0.29, df=2, p=0.76). Little variation in *G. chilensis* existed within sites (Two-Factor ANOVA without replication; F=0.13, df=2, p=0.88) and between sites (F=2.97, df=6, p=0.05).

Figures 4.18 and 4.19 show dry weight biomass of *U. lactuca* and *G. chilensis* measured in the laboratory. Biomass of *U. lactuca* was particularly high at sites 2, 3, 4 and 8a, but *G. chilensis* was comparatively lower than at sites 5, 6 and 7. There was an insignificant difference for *U. lactuca* within sites (Two-Factor ANOVA without replication; F=2.71, df=2, p=0.10) but significant differences between sites (F=3.43, df=6, p<0.04). There was insignificant variation within sites for *G. chilensis* (Two-Factor ANOVA without replication; F=0.63, df=2, p=0.54) and insignificant variation between sites (F=1.86, df=6, p=0.17).

When Figures 4.14 to 4.19 were compared for differences in variation across the measured field wet weight, laboratory wet weight and laboratory dry weight, there was no clear difference in the variations for *U. lactuca* or *G. chilensis*. While biomass was the primary factor/property/characteristic measured in the field, other factors such as percent cover and attachment of macroalgae to sediment were also measured. Data from the field in relation to these two factors are shown in Appendix 2, along with the biomass data. Of most interest to the results is the data gathered in relation to macroalgal attachment to sediment. Nearly all of the *U. lactuca* and *G. chilensis* is unattached. In the area sampled, this is the likely cause for the high variability of macroalgae between sites.

Figures 4.20 and 4.21 are plots of field wet weight biomass of *U. lactuca* and *G. chilensis* against percent cover output in *SAS*. The reason behind this was to test the hypothesis that biomass could be inferred from percent cover of macroalgae alone. Results show that any correlation concluded between coverage and biomass of either macroalgal species would be unwise because of the variation in biomass, particularly when cover is 100%. This finding agrees with those of Knox and Kilner (1973), Bressington (2003) and Nezlin et al. (2007).

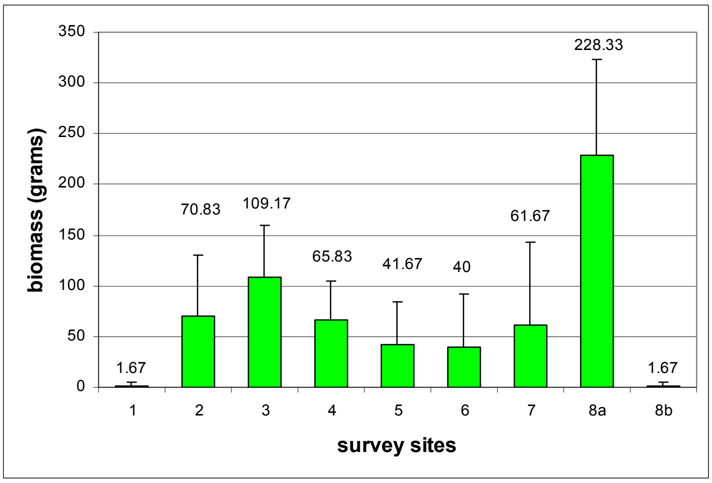


Figure 4.14 Wet weight biomass of *U. lactuca* measured in the field.

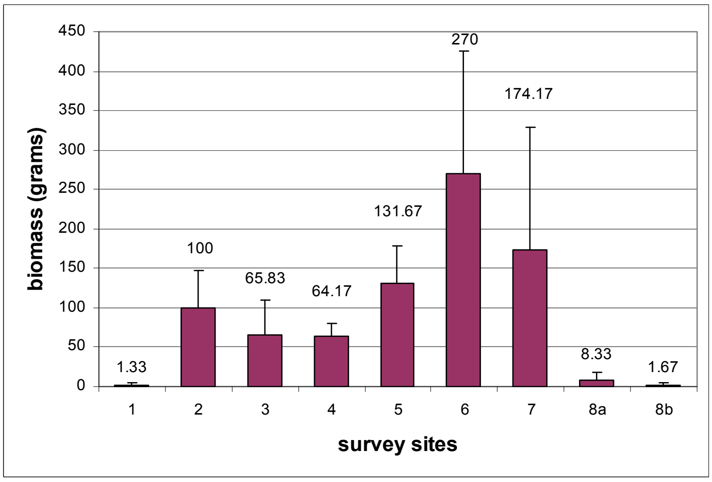


Figure 4.15 Wet weight biomass of *G. chilensis* measured in the field.

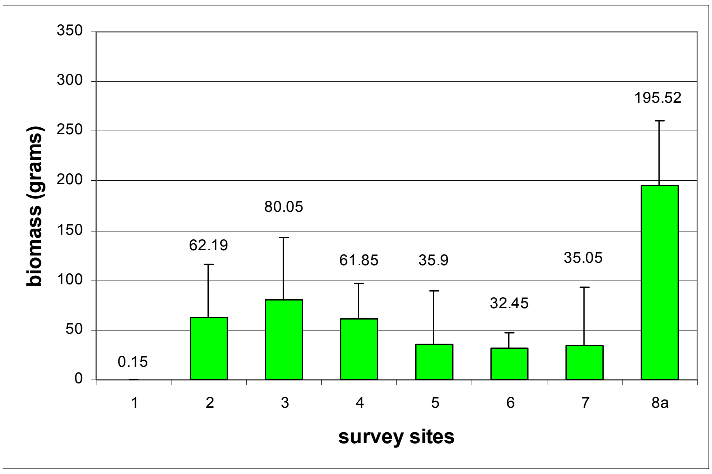


Figure 4.16 Wet weight biomass of *U. lactuca* measured in the laboratory.

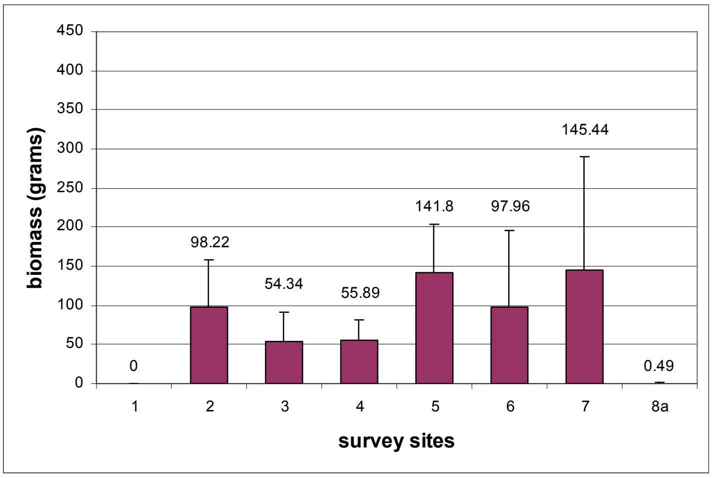


Figure 4.17 Wet weight biomass of *G. chilensis* measured in the laboratory.

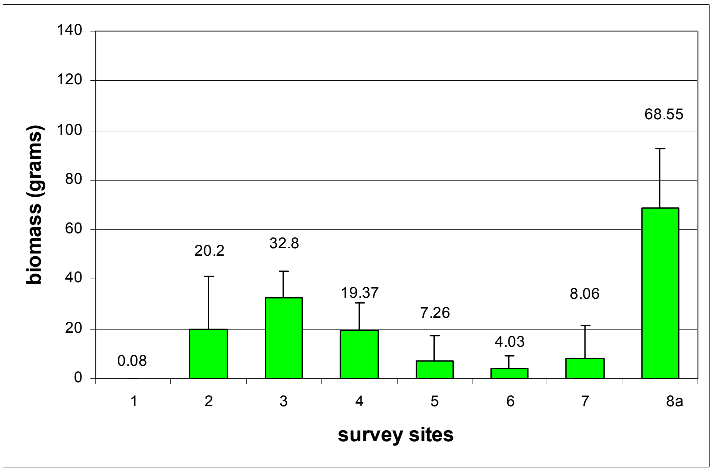


Figure 4.18 Dry weight biomass of *U. lactuca.*

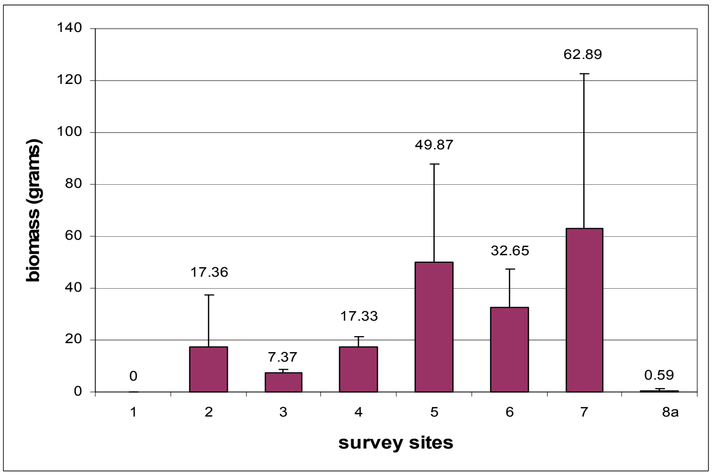


Figure 4.19 Dry weight biomass of *G. chilensis.*

Ulva biomass

Gracilaria biomass

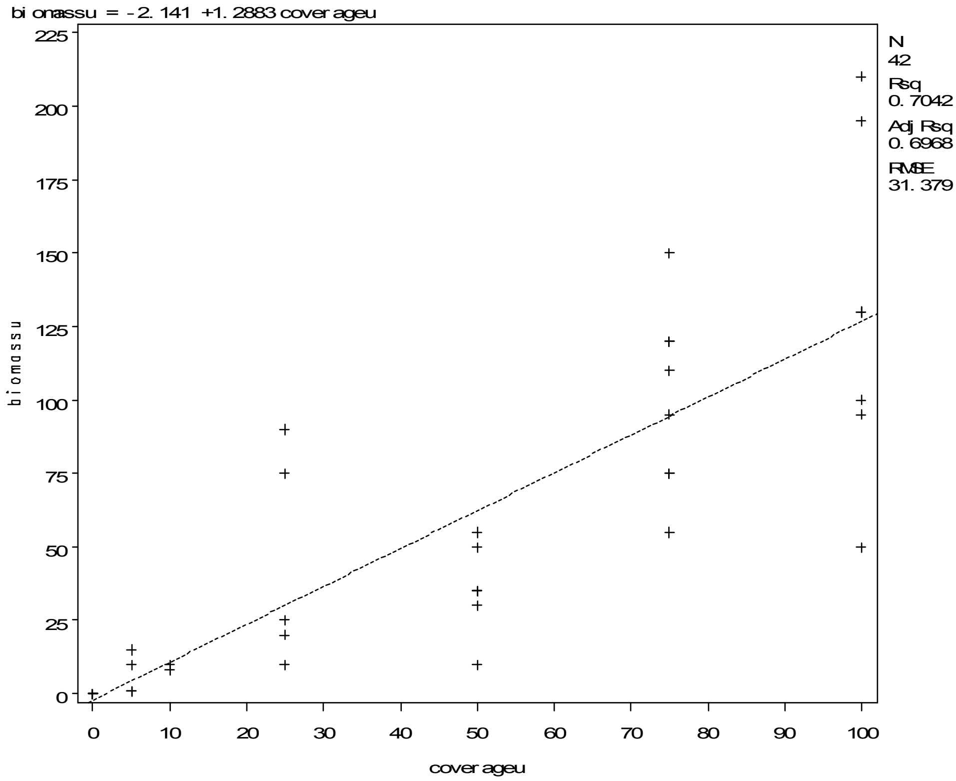


Figure 4.20 Correlation between *U. lactuca* biomass and coverage.

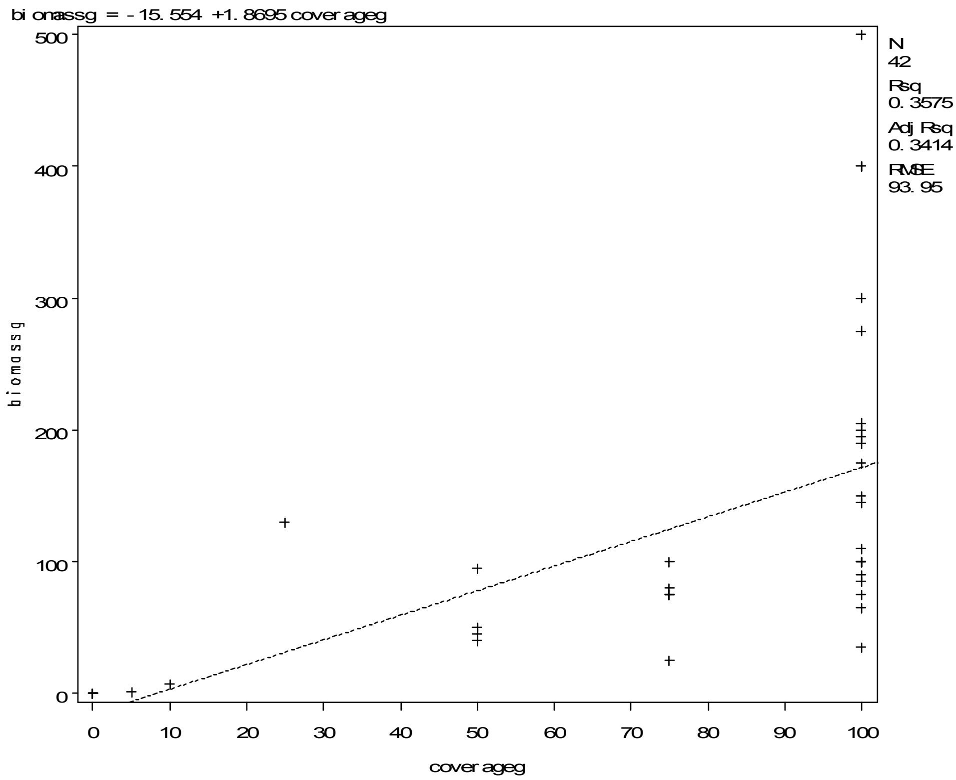


Figure 4.21 Correlation between *G. chilensis* biomass and coverage.

From the biomass results a dry weight (lab) to wet weight (field) ratio was calculated. For *U. lactuca* the ratio is 0.26 and for *G. chilensis* it is 0.23. Table 4.2 shows the mean wet weights measured in the field, lab, and the dry weights measured in the lab. The purpose of this is to show the biomass in grams per quadrat against the biomass in kg/m² for comparison with early Avon-Heathcote Estuary macroalgae studies.

Table 4.2 g/qt to kg/m² conversions for biomass. Note qt refers to quadrat.

		Field wet weight				Laboratory wet weight				Laboratory dry weight			
		U. lactuca g/qt	kg/m²	*G. chilensis* g/qt	kg/m²	*U. lactuca* g/qt	kg/m²	*G. chilensis* g/qt	kg/m²	*U. lactuca* g/qt	kg/m²	*G. chilensis* g/qt	kg/m²
survey sites	1	1.67	0.03	1.33	0.02	0.15	0.00	0	0.00	0.08	0.00	0	0.00
	2	70.83	1.13	100	1.60	62.19	1.00	98.22	1.57	20.2	0.32	17.36	0.28
	3	109.17	1.75	65.83	1.05	80.05	1.28	54.34	0.87	32.8	0.52	7.37	0.12
	4	65.83	1.05	64.17	1.03	61.85	0.99	55.89	0.89	19.37	0.31	17.33	0.28
	5	41.67	0.67	131.67	2.11	35.9	0.57	141.8	2.27	7.26	0.12	49.87	0.80
	6	40	0.64	270	4.32	32.45	0.52	97.96	1.57	4.03	0.06	32.65	0.52
	7	61.67	0.99	174.17	2.79	35.05	0.56	145.44	2.33	8.06	0.13	62.89	1.01
	8a	228.33	3.65	8.33	0.13	195.52	3.13	0.49	0.01	68.55	1.10	0.59	0.01
	8b	1.67	0.03	1.67	0.03								

4.4 Discussion of Results

4.4.1 Macroalgal Coverage

Aerial photography taken at 1000 ft using data captured in the visible spectrum has provided more useful results for mapping the macroalgae in the Avon-Heathcote Estuary than any other previous studies. The results from Figure 4.11 are useful for determining canopy surface cover. The classes used in the classification can only be defined as '*U. lactuca* dominates' or '*G. chilensis* dominates' because there is only certainty of the macroalgal cover on the canopy surface and not entire certainty as to what is below the canopy surface. While the classification 'Bare Sediment' indicates that this is the only feature, it would be incorrect to assume so because of minor macroalgal accumulations that occur in places. The inability of the low resolution overview image to pick up these minor macroalgal accumulations is a limitation of mapping macroalgae using aerial photography. Accordingly, the estimates of macroalgal cover using aerial photography are conservative since the classification is not sensitive to accumulations of macroalgae with less than 75 % cover (Finkbeiner et al. 2001; Nezlin et al. 2007).

The secondary navigation equipment was used to georeference the images, but as previously mentioned, spatial accuracy is an issue. The maximum inaccuracy of 40 m on the ground is not concerning because there was no attempt to correlate point locations on the ground with points on the aerial photography. The authors conclude that with ongoing research by the GRC to reduce the error associated with not using GCPs, this should prove to be an effective way of carrying out aerial photography, because this allows more time to carry out ground-truthing. The other issue in terms of spatial accuracy is the overlapping of images rather than mosaicking of the images. As a result, some of the images do not adequately coincide with points in adjacent images. The supervised classifications therefore have some additional error associated with non-mosaicking.

4.4.2 Macroalgal Biomass

Wet weights were measured both in the laboratory and in the field. The main reason behind measuring wet weights again in the laboratory was for more accurate comparison with the dry weight biomass. If anything, the wet weights in the field tend to be overestimated compared with the results obtained in the laboratory. This can be put down to excess water contained in the measured field sample and mud contained within the sample, which was washed off in the laboratory. The most time-consuming aspect of the biological sampling was weighing the wet weights of each individual sample separately in the field. This was due to the difficulty of measuring macroalgal weights in the field because it took considerable time for the electronic balance to register zero grams. From the statistical p-values obtained by carrying out ANOVA tests, dry and wet weights measured in the laboratory have insignificant variation within sites for both macroalgal species. *U. lactuca* wet and dry weights for the differences between sites were both significant and *G. chilensis* wet and dry weights were both significant. Field wet weights were insignificant for both macroalgal species within sites, but between sites there were significant differences for *G. chilensis*, which reflects inaccuracy in the wet weights due to water and mud present in the field (mud is particularly associated with *G. chilensis*). Comparison with Williams (1960) reveals that the biomass of *Ulva* spp. was a lot higher in the late 1950s than it is now, based on the kg/m^2 measurements. It is clear from Figures 4.14 to 4.19 that wet weight is just as useful for obtaining biomass of both genera of macroalgae because the standard deviation bars are proportionally similar for mean field wet weight, laboratory wet weight and dry weight. This finding is significant since it means that the more rapid field measurements can be conducted in future studies without the need for subsequent lengthy laboratory analyses.

4.5 Conclusion

This chapter has outlined in detail a methodology that has been trialled successfully. Results from a supervised classification have shown that it is possible to accurately map the coverage of different macroalgal species in the Avon-Heathcote Estuary. There was high coverage and biomass of *G. chilensis* along Humphreys Drive and opposite the Mount Pleasant Yacht Club. Cover and biomass of *U. lactuca* tended to be highest around Sandy Point. While cover is able to be mapped using aerial photography, at this stage biomass can only be quantified by carrying out extensive ground-truthing.

Chapter 5: General Discussion

Since the 1950s, macroalgae growth in estuarine environments worldwide has increased markedly, including the Avon-Heathcote Estuary (Mackenzie 2005). At the Avon-Heathcote Estuary, ground-based macroalgal cover surveys, with a focus on green algae distribution (*Ulva* spp. and *Enteromorpha* spp.) date back to the early 1950s when the first survey was conducted by Bruce (1953). Areas that were traditionally high in green algae cover from the 1950s to the 1970s were McCormacks Bay, Sandy Point, Discharge Point and Humphreys Drive (Knox and Kilner 1973). These early ground-based surveys provide a strong indication that the 1960s were the worst recorded times for green algae growth in the Avon-Heathcote Estuary. The collation and evaluation of these maps for macroalgal coverage achieved the first aim of this research, to collate and evaluate existing maps of macroalgal coverage and/or biomass.

The macroalgal changes in cover over the past ten years were mapped only for 2001, 2002, and 2003 (Robertson et al. 2002; Landcare Research 2002; Bressington 2003) because maps were only produced in the summer months of these years. No biomass measurements were made during the last ten years, although Bressington (2003) did show that there are significant changes in biomass intra-annually. Ground-based CCC monitoring surveys allowed only general intra-annual and inter-annual changes to be observed. Plotting the changes in macroalgal cover through maps and graphical plots achieved the second aim of this research, to plot changes in biomass and coverage over the last ten years.

Analysis of ground-based surveys and remote sensing surveys have shown that a variety of techniques have been used to map macroalgal cover in the Avon-Heathcote Estuary. Internationally there has been considerable emphasis over the last decade towards developing remote sensing techniques for mapping macroalgal cover (Guichard et al. 2000; Clinton et al. 2001; Cole et al. 2002; Green 2005; Nezlin et. al 2007). Results of the evaluation of past mapping techniques, including those used at the Avon-Heathcote Estuary and internationally, achieved the third aim of this project, to determine and evaluate the mapping techniques used to date.

According to Nezlin et al. (2007), the development of remote sensing techniques for mapping macroalgae has occurred due to the potential for increased accuracy over traditional ground-based surveys in providing synoptic or regional overviews. Further, in large estuarine environments, remote sensing can be more efficient and cost-effective than ground-based methods alone (Nezlin et al. 2007). Remote sensing techniques employed in past studies of the Avon-Heathcote Estuary include satellite imagery and aerial photography. A review of these studies indicates that aerial photography has higher potential for mapping macroalgal cover due to the higher resolution of this type of data.

This research has led to the development and trial of a detailed methodology to map macroalgal cover and biomass using high resolution imagery in the Avon-Heathcote Estuary which achieves the fourth aim of this research. Aerial photography taken at 1000 ft using data captured in the visible spectrum has provided the most useful macroalgae cover mapping method yet. Results from the development of this method indicate that there is not enough evidence to suggest a correlation between biomass and coverage, therefore any conclusions made about biomass from cover mapped using aerial photography are unwise. Currently macroalgae biomass can only be measured using extensive ground-truthing but there is potential in the future to investigate the usefulness of infrared imagery in mapping algae biomass.

Chapter 6: Recommendations for Future Macroalgae Mapping in the Avon- Heathcote Estuary

The methodology outlined in Chapter 4 is the recommended way for monitoring macroalgal coverage and biomass in the Avon-Heathcote Estuary and with minor amendments, this is the method that should be carried out in the future. The following general and detailed recommendations are a direct result of the outcomes obtained from the field trial.

1. General

(i) ECAN and the CCC should work together with the GRC to modify and improve the macroalgae mapping techniques in the Avon-Heathcote Estuary outlined in Chapter 4.

2. Timing of surveys

(i) Mapping macroalgal biomass and coverage should commence in July 2008 in order to observe changes throughout the season and to observe these before the ocean outfall is operational and estuary discharges terminate. Mapping of the winter crop of algae will enable predictions to be made about upcoming summer biomass. The most appropriate dates for surveys based on tidal prediction data from NIWA (2008) for July 2008 are from July 1 to 8 or July 22 to 28. These dates coincide approximately with spring tides.

(ii) Mapping of the macroalgae in the Avon-Heathcote Estuary is recommended at least four times a year (i.e. once every three months). This is required in order to accurately assess the seasonal changes in macroalgal coverage and biomass.

(iii) The fieldwork should be planned in the same week of each month, with appropriate contingency days made. Where possible the week should coincide with a spring tide.

3. Aerial photography

(i) Imagery should be taken at 2000 ft to increase the coverage of individual images. Imagery should also be taken at 2500 ft and 3000 ft to observe the effects on data quality the first time that monitoring surveys are carried out.

(ii) Imagery across all of the Avon-Heathcote Estuary should be carried out. Imagery taken at 2000 ft should take approximately one hour.

(iii) The time-lapse trigger box should be adjusted to take images at 3-4 second intervals in order to achieve approximately 60 % overlap at the ends. Flight paths should also be flown so that it allows 30 % overlap of images at the sides.

(iv) For the purposes of mapping the coverage of macroalgae, there is no requirement of GCPs in future mapping studies. If, however, there is future requirement for higher precision than was used in the methodology trial, then the number of GCPs required will be determined by the level of accuracy required and the coverage of the images.

(v) Colour infrared photography can increase the ability of researchers to distinguish cover types by emphasising the contrast between vegetated and non-vegetated surfaces (Nezlin et al. 2007) and its potential should be investigated concurrently with future monitoring surveys.

(vi) The potential for using infrared imagery to collect data in the infrared spectral bands for mapping macroalgal biomass also needs to be investigated. The GRC currently have a *Geospatial Systems Multispectral 4100* sensor, which has RGB colour for colour imagery applications and colour infrared for multispectral purposes (Geospatial Systems Incorporated 2006). Trials for analysing the usefulness of infrared spectral bands for mapping macroalgae in the Avon-Heathcote Estuary should be carried out at the same time as future monitoring surveys and as soon as possible for an assessment for its potential to map biomass.

(vii) The method for mapping biomass through ground-based surveys should be not discontinued until any remote sensing method is proven to be successful.

(viii) Aerial photography should be carried out under calm weather conditions. Ideally it would be carried out on a day with high cloud to reduce reflection and with low wind speeds. The latter is particularly important when using a microlight, because when wind speeds get above 25-30 kph, it can become dangerous for the pilot. Ultimately the decision to fly is down to the pilot's discretion. Broken cloud must be above the flying altitude of the microlight. Aerial photography should also be taken around the middle of the day, when the sun angle is high (greater than 30º above the horizon) to reduce glare.

4. Image Processing

(i) To increase the accuracy of the classifications a mosaiced image with all the individual images should be created. The resolution of the overview mosaic should be increased further than the overview map (Figure 4.9) to less than 1 m.

5. Image Classification

(i) Particularly in the winter and spring months, when *Enteromorpha* is abundant, both *U. lactuca* and *Enteromorpha* will be grouped together as a single class when using aerial photography. Mapping macroalgae in early spring will enable *Enteromorpha* to be mapped when there is very little, if any occurrence of other macroalgae.

6. Ground-based Biological Sampling

(i) Biomass should be sampled at a variety of locations, using 200 m² survey sites. The coordinates for the locations of the survey sites should be recorded for future reference. Survey sites for measuring biomass should include selected areas near the mouth of the estuary and near locations of river inputs as well as McCormacks Bay.

(ii) Sampling should be carried out over one tidal cycle to obtain the most accurate results. This is due to the mobility of the unattached macroalgae, which, after stormy weather, can change distribution substantially.

(iii) Wet weight measurements in the field are recommended to continue because it is too time consuming to take all samples back for analysis in the laboratory. No more than three samples from each survey site need to be taken back to the laboratory for calculating a conversion factor from wet weight and dry weight.

Chapter 7: Conclusions

This research has documented previous studies, all involving ground-based surveys, for mapping the macroalgae in the Avon-Heathcote Estuary. While these surveys have successfully identified total macroalgal cover (mostly green algae distribution), inconsistent sampling sites, classifications, methods and incomplete data do not effectively map macroalgae inter-annually and intra-annually. Recent international literature for mapping macroalgal coverage and biomass has shown that remote sensing techniques are more effective than traditional ground-based surveys. This is due to the ability to cover areas not easily accessible by foot and the ability to gather data on extensive areas in a short space of time.

Recent attempts to map the Avon-Heathcote Estuary using satellite imagery and aerial photography have shown the potential for mapping macroalgae. Satellite imagery is limited by suitable atmospheric conditions, the inability to separate individual macroalgal species, and most importantly in terms of distinguishing between macroalgal species, low resolution imagery. Where aerial photography has been used to attempt to map macroalgal species, the resolution of the imagery was too low.

It has been shown that aerial photography taken by a microlight at 1000 ft is an accurate enough way for collecting data. Supervised classification of low resolution imagery is an effective way to map the cover of the dominant macroalgal species. It is important to note that ground-truthing is essential for classifying the images according to colour and tone.

Colour aerial photography is not useful for inferring biomass of macroalgae. Measuring the biomass of the macroalgal species at this stage can only be done by random biological sampling. There is future potential for mapping biomass using infrared imagery. The results show that there is high cover and biomass of *G. chilensis* along Humphreys Drive and opposite the Mount Pleasant Yacht Club. Cover and biomass of *U. lactuca* tends to be highest around Sandy Point. Cover of *U. lactuca* extends to the northern side of the Heathcote Channel.

A series of recommendations have been suggested to improve the methodology and these should be implemented in future macroalgal mapping. The methodology itself should be viewed as the first step in achieving the end goal to map macroalgae biomass and coverage as effectively and efficiently as possible. In this way it will be possible to monitor the changes, if any, in macroalgal cover and biomass as a result of ocean outfall becoming operational.

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Appendix 1: GCP Data

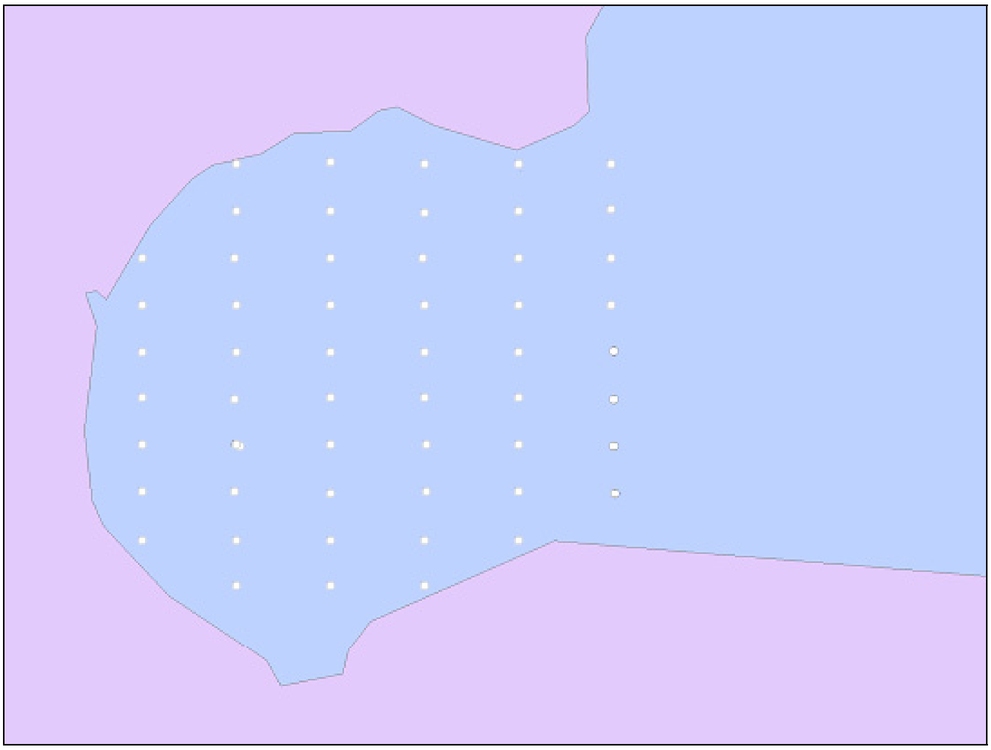

Figure A1.1: Planned locations for GCPs prior to field surveying (54 in total).

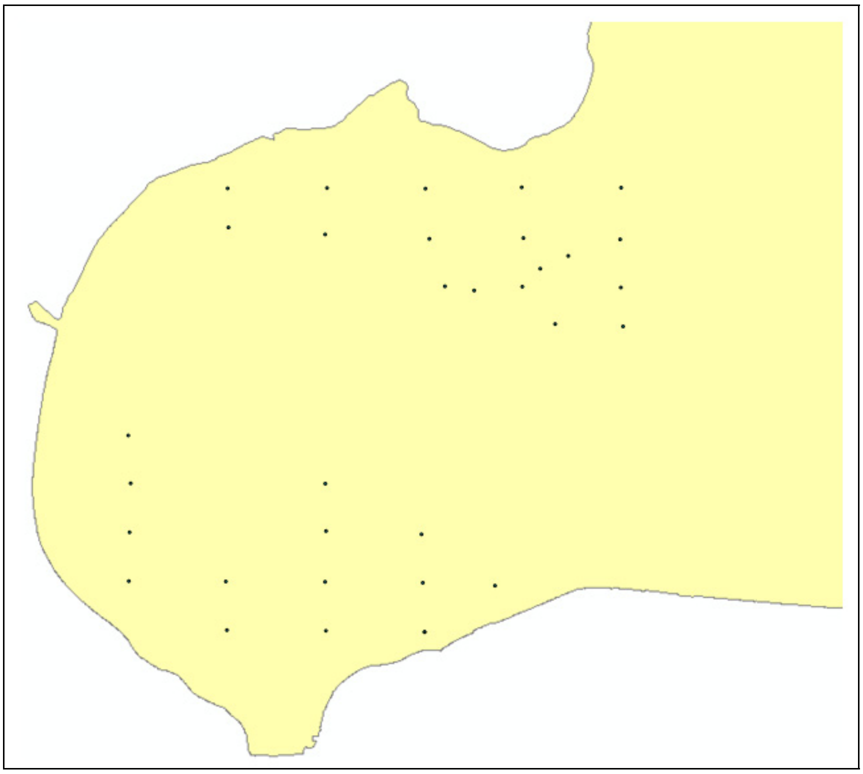

Figure A1.2: GCPs measured in field area (32 in total).

Table A1.1: Coordinates for all GCPs.

Name	Northing	Easting
1	804710.000	399170.000
2	804711.000	398970.000
3	804711.000	398770.000
4	804712.000	398570.000
5	804713.000	398370.000
6	804610.000	399169.000
7	804611.000	398969.000
8	804611.000	398769.000
9	804612.000	398569.000
10	804613.000	398369.000
11	804510.000	399169.000
12	804511.000	398969.000
13	804511.000	398769.000
14	804512.000	398569.000
15	804513.000	398369.000
16	804513.000	398169.000
17	804410.000	399169.000
18	804411.000	398969.000
19	804411.000	398769.000
20	804412.000	398569.000
21	804413.000	398369.000
22	804413.000	398169.000
23	804310.000	399168.000
24	804311.000	398968.000
25	804311.000	398768.000
26	804312.000	398568.000
27	804313.000	398368.000
28	804313.000	398168.000
29	804210.000	399168.000
30	804211.000	398968.000
31	804211.000	398768.000
32	804212.000	398568.000
33	804213.000	398368.000
34	804213.000	398168.000
35	804110.000	399168.000
36	804111.000	398968.000
37	804111.000	398768.000
38	804112.000	398568.000
39	804113.000	398368.000
40	804113.000	398168.000
41	804010.000	399167.000
42	804011.000	398967.000
43	804011.000	398767.000
44	804012.000	398567.000
45	804013.000	398367.000
46	804013.000	398167.000
47	803911.000	398967.000
48	803911.000	398767.000
49	803912.000	398567.000
50	803913.000	398367.000
51	803913.000	398167.000
52	803811.000	398767.000

53	803812.000	398567.000
54	803813.000	398367.000

Appendix 2: Raw Biological Data

Table A2.1: Percent cover of *U. lactuca*.

U. lactuca

		Samples					
		1	2	3	4	5	6
Survey sites	1	0	0	5	5	0	10
	2	100	75	0	50	50	75
	3	100	75	75	100	100	75
	4	100	50	25	50	75	25
	5	0	5	25	50	75	50
	6	25	25	0	75	5	10
	7	100	50	0	75	0	100
	8a	100	100	100			
	8b				0	0	5

Unattached
Attached

Table A2.2: Percent cover of *G. chilensis*.

G. chilensis

		Samples					
Survey sites	1	0	0	5	0	0	10
	2	100	75	100	100	100	50
	3	100	75	100	25	50	50
	4	100	75	50	75	75	50
	5	100	100	100	100	75	100
	6	100	100	100	100	100	100
	7	0	100	100	50	100	50
	8a	25	5	0			
	8b				0	0	5

Unattached
Attached

Table A2.3: Field wet weight biomass of *U. lactuca* (in grams).

U. lactuca

		Survey sites								
		1	2	3	4	5	6	7	8a	8b
Samples	1	0	130	50	100	0	10	210	125	
	2	0	75	95	30	15	90	10	310	
	3	1	0	110	20	25	0	0	250	
	4	1	35	130	50	55	120	55		0
	5	0	35	195	120	120	10	0		0
	6	8	150	75	75	35	10	95		5

Table A2.4: Field wet weight biomass of *G. chilensis* (in grams).

G. chilensis

	Survey sites								
	1	2	3	4	5	6	7	8a	8b
1	0	85	110	65	195	205	0	20	
2	0	75	25	80	175	150	300	5	

Samples	3	1	190	35	40	145	400	200	0	
	4	0	100	130	75	75	500	50		0
	5	0	100	50	75	100	275	400		0
	6	7	50	45	50	100	90	95		0

Table A2.5: Laboratory wet weight biomass of *U. lactuca* (in grams).

U. lactuca		Survey sites							
		1	2	3	4	5	6	7	8a
	1	0	93.12	17.57	100.03	0	3.98	102.3	120.53
	2	0	93.45	143.61	55.61	9.61	28.47	2.86	239.44
Samples	3	0.45	0	78.98	29.91	98.08	0	0	226.6

Table A2.6: Laboratory wet weight biomass of *G. chilensis* (in grams).

G. chilensis		Survey sites							
		1	2	3	4	5	6	7	8a
	1	0	74.04	96.47	65.73	198.6	267.18	0	0.95
	2	0	54.4	30.32	74.93	150.28	130.01	276.1	0.3
Samples	3	0	166.22	36.22	27	76.51	319.74	217.35	0

Table A2.7: Dry weight biomass of *U. lactuca* (in grams).

U. lactuca		Survey sites							
		1	2	3	4	5	6	7	8a
	1	0	42.68	44.6	32.29	0	2.26	23.24	82.99
	2	0	17.37	24.81	14.5	3.14	9.84	0.95	81.93
Samples	3	0.24	0	28.98	11.32	18.65	0	0	40.73

Table A2.8: Dry weight biomass of *G. chilensis* (in grams).

G. chilensis		Survey sites							
		1	2	3	4	5	6	7	8a
	1	0	2.66	7.61	19.35	92.61	16.6	0	1.56
	2	0	39.9	6.11	20.08	36.58	35.2	118.45	0.2
Samples	3	0	9.51	8.4	12.55	20.41	46.15	70.23	0

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